Sedentary Behaviour in Morbidly Obese Pregnant Women

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Abstract

Introduction

Obesity during pregnancy is linked to many negative health effects for mothers and offspring. The majority of interventions with obese pregnant women based on physical activity have had limited success suggesting alternative approaches are needed. Sedentary behaviour is defined as waking activities that expend very low energy, 1.5 metabolic equivalents or below, while reclining, lying or sitting. Spending too much time sedentary has been identified as a risk factor for health, regardless of physical activity levels. We hypothesised that targeting sedentary behaviour may be a suitable alternative to reduce health risks during gestation among pregnant women who are morbidly obese (defined as body mass index, BMI>40 Kg/m^2).

Aim and objectives

The aim was to explore sedentary behaviour among obese pregnant women and to propose an intervention to reduce the time obese pregnant women spend sedentary, through an active sitting exercise intervention.

To conduct a systematic review of the literature to determine the proportion of time spent in sedentary behaviour among pregnant women, and the association of sedentary behaviour with pregnancy outcomes in mothers and offspring.

To estimate total energy expenditure, and energy expended in sedentary activities in morbidly obese and lean pregnant women.

To assess the feasibility of an active sitting exercise intervention for morbidly obese pregnant women, designed using a patient involvement in research method.

Systematic Review

A systematic review of the literature reporting sedentary behaviour during pregnancy and its effects on pregnancy outcomes was conducted. Twenty six publications were included in the systematic review up until October 2015, and a further 18 were identified in the update completed in April 2018. Pregnant women spent at least 50% of their time in sedentary activities. Associations between increased time sedentary and higher risk of macrosomia, higher risk of preeclampsia, higher risk of developing gestational diabetes mellitus, and larger new-born abdominal circumference were observed, as the main findings. Most of included studies scored an intermediate quality, only two of the 44 studies scored a good quality.

Cross-sectional study.

A cross-sectional study was conducted, using the Pregnancy Physical Activity Questionnaire (PPAQ), and the Actical accelerometer, to assess energy expenditure, and energy expended in sedentary behaviour. Based on the PPAQ, women who were morbidly obese expended significantly more energy per day, as total expenditure, than lean pregnant women, which was confirmed by the Actical. During sedentary behaviour lean pregnant women expended significantly less energy than morbidly obese pregnant women, based on the PPAQ. No differences were observed between lean and morbidly obese pregnant women in the proportion of time spent in sedentary activities, nor in time sedentary.

Exercise Intervention Design

A patient involvement in research approach was used to design an active sitting exercise intervention for morbidly obese pregnant women. Twenty three women took part in the design of the intervention, enabling design of a final protocol including six exercises, to be performed in two sets of 10 repetitions.

Active sitting exercise intervention

An intervention based on active sitting exercises for morbidly obese pregnant women to reduce sedentary time was conducted to assess the feasibility.

Thirty morbidly obese pregnant women were recruited of whom 20% completed the exercise intervention. The main reason not to complete the intervention was lack of time.

Conclusion

A better understanding of sedentary behaviour is needed for the design of effective interventions to help to reduce the adverse effects of morbid obesity on pregnancy, especially as prevalence is growing. More time spent in light intensity activities rather than in sedentary behaviour may play a role as contributing to reduce those risks associated with obesity during pregnancy, and to reduce time spent sedentary.

Participants have shown real interest in helping to design an effective exercise intervention. Involving and empowering participants in how to take care of themselves as part of the intervention helps to increase their commitment. Giving participants the tools to take care of their own health and their babies' should be considered as part of the intervention with very obese pregnant women. Providing the information in how and why exercise might help, and basing the intervention in giving participants easy and realistic tasks that they could do on their own and around their own environment, will help to increase their commitment. This appears to be a feasible and effective strategy.

Lay Summary

Introduction

Obesity during pregnancy is related to many negative health effects for mothers and babies. Most interventions based on increasing levels of physical activity for obese pregnant women have not succeeded. This has made researchers look for other methods to help obese pregnant women to reduce risks associated with obesity during pregnancy. Spending too much time in sedentary activities, meaning activities that require very low energy, such as sitting or lying, is also considered a risk factor for health, even for people who regularly practice physical activity. We thought that focusing on the time spent on sedentary activities might be helpful for very obese pregnant women to decrease the risks they are exposed during pregnancy.

Aim and objectives

The main aim was to investigate sedentary behaviour among obese pregnant women and to propose an intervention to reduce the time obese pregnant women spend sedentary, through an active sitting exercise intervention.

We wanted to review the literature to know how much time pregnant women spend in sedentary activities, and to find out whether or not time sedentary is associated with pregnancy outcomes for mothers and babies.

We wanted to know how much energy very obese pregnant women and lean pregnant women expend in the total daily activities and particularly in sedentary activities.

We wanted to design an exercise intervention during pregnancy based on exercises to be performed whilst sitting with very obese pregnant women. We also wanted to learn if the intervention would be feasible.

Results

We reviewed the literature looking for studies reporting time sedentary during pregnancy or publications studying the effects of time sedentary on pregnancy results. Twenty-six studies were included in the review up until October 2015, and a further eighteen were identified in the update completed in April 2018. Pregnant women spent at least half of their time awake in sedentary activities. Negative effects for health were observed when too much time sedentary, such as higher risk of babies weighing more than four kilograms, having a larger waist circumference, and more risk of developing gestational diabetes mellitus (defined as high blood sugar that develops during pregnancy and usually disappears after giving birth).

The Pregnancy Physical Activity Questionnaire, and the Actical accelerometer (a device that measures body movements very accurately including variables as range and the velocity of the movements) were employed to assess the energy expended in total daily activities and in sedentary activities, among lean and very obese pregnant women. The results showed that very obese pregnant women expended considerably more energy per day than lean pregnant women. In sedentary activities the PPAQ showed that very obese pregnant women expended much more energy than lean pregnant women, however looking at the proportion of time spent in sedentary activities, no differences were found between lean and very obese pregnant women.

To design an exercise intervention for very obese pregnant women based on exercises to be performed mostly sitting, twenty-three women participated. A final strategy based on six exercises, to be done in two sets of ten repetitions was constructed by the participants working with the researchers. The feasibility of using this exercise intervention was tested with thirty very obese pregnant women. Twenty per cent of the women completed the exercise intervention. The main reason not to complete the intervention was lack of time.

Conclusion

The number of very obese pregnant women is rising. We have learnt that they and their babies are in high risk of negative health effects, setting the necessity for new and effective alternatives aiming to reduce those risks. As too much time in sedentary activities is also associated with negative effects during pregnancy, we believe that focusing on reducing that time is a suitable target for intervention. Exchanging sedentary activities with higher intensity activities, such as walking or standing, may help to reduce those risks associated with obesity during pregnancy, and to reduce time spent in sedentary activities.

Participants demonstrated that they are interested in helping to design an effective exercise intervention. Giving participants the tools to take care of their own health and their babies should be considered as part of the intervention with very obese pregnant women. Providing the information in how and why exercise might help, and basing the intervention in giving participants easy and realistic tasks that they could do on their own and around their own environment, will help to increase their commitment. This appears to be a feasible and effective strategy.

Table of Contents

Abstract 3

Lay Summary 7

Table of Contents 11

Declaration 15

Acknowledgements 17

Dedication 19

Publications, Presentations and Posters 21

List of Abbreviations 23

List of Tables 25

List of Figures 27

Chapter I. Introduction 29

1.1. Obesity 31

1.1.1. Obesity and pregnancy 32

1.2. Energy expenditure 37

1.2.1. Energy expenditure and physical activity assessment methods 40

1.3. Physical activity in obese pregnant women 51

1.3.1. Patterns of physical activity among obese pregnant women 51

1.3.2. Recommended physical activity for obese pregnant women 52

1.3.3. Benefits of exercising during pregnancy 55

1.3.4. Adverse effects of exercise during pregnancy 64

1.3.5. Barriers to exercise in obese pregnant women. 69

1.4. Sedentary behaviour 71

1.4.1. Definition of Sedentary behaviour 71

1.4.2. Methods to assess sedentary behaviour 72

1.4.3. Prevalence of sedentary behaviour 72

1.4.4. Consequences of sedentary behaviour for health 75

1.4.5. Physiology of sedentary behaviour 81

1.4.6. Sedentary behaviour and pregnancy 83

1.4.7. Interruptions to sedentary time 84

1.4.8. Interventions to reduce sedentary behaviour............................. 88

1.4.9. Summary 90

1.5. Hypothesis 91

1.6. Aim and Objectives 91

Chapter II. Sedentary behaviour during pregnancy: A systematic review 93

2.1. Introduction 95

2.2. Systematic review until October 2015 96

2.2.1. Manuscript 97

2.2.2. Conclusion 133

2.3. Systematic review update from October 2015 to April 2018 134

2.3.1. Findings 134

2.4. Comparisons between reviews... 146

2.5. Conclusion 149

Chapter III. Clinical Methods 151

3.1. The Antenatal Metabolic Clinic 153

3.2. Ethical Approval 154

3.3. Participants.. 155

3.3.1. Sample size 155

3.3.2. Criteria for inclusion 155

3.3.3. Recruitment 156

3.4. Collection of data 158

3.4.1. Measurements 158

3.5. Data analysis 163

Chapter IV. Activity behaviour in lean and morbidly obese pregnant women . 165

4.1. Introduction 167

4.2. Activity behaviour in lean and morbidly obese pregnant women. 167

4.3. Manuscript 169

4.4. Conclusion 190

Chapter V. Design of an active sitting intervention, to reduce sedentary behaviour in morbidly obese pregnant women, using patient involvement in developing the research strategy.. 195

5.1. Introduction 197

5.1.1. Interventions with obese pregnant women. 197

5.1.2. Involving participants in the study design.................................. 198

5.1.3. Involving pregnant women in the study design............................ 199

5.1.4. Antenatal Metabolic Clinic. 200

5.2. Aim.. 201

5.3. Methods 202

5.3.1. 1st Stage: Sedentary behaviour and physical activity in pregnancy.... 202

5.3.2. 2nd Stage: Intervention Design. 203

5.4. Data analysis/synthesis 207

5.5. Results... 207

5.5.1. 1st Stage: Questionnaire... 207

5.5.2. 2nd Stage: Intervention Design 208

5.6. Discussion 213

Chapter VI. OPALS feasibility study 217

6.1. Introduction 219

6.2. Aim.. 223

6.3. Methods 223

6.3.1. Ethics Approval.. 223

6.3.2. Setting.. 223

6.3.3. Sample.. 224

6.3.4. Data collection 225

6.3.5. Exercise intervention 227
6.3.6. Data analysis 228
6.4. Results 229
6.4.1. Intervention 229
6.4.2. OPALS Feasibility Questionnaire 229
6.5. Discussion 234
Chapter VII. Discussion 237
7.1. Discussion 239
7.2. Strength and Weaknesses 241
7.3. Gaps in the Literature 242
7.4. Future Directions 245
References 247
Appendices
Appendix 1. Sedentary Behaviours during pregnancy: a systematic review.
Appendix 2. Pregnancy Physical Activity Questionnaire.
Appendix 3. Questionnaire: Physical Activity Information in Pregnancy.
Appendix 4. Exercise Intervention Feedback Form.
Appendix 5. OPALS Feasibility Questionnaire.
Appendix 6. Activity behaviours in lean and morbidly obese pregnant women.
Appendix 7. OPALS Study Activity Diary.

Declaration

I declare that the composition of this thesis has been composed solely by myself. I am aware of and understand the university's policy on plagiarism and I certify that this thesis is my own work, except where explicitly stated otherwise in the text.

The work presented in Chapter II was previously published in the International Journal of Behavioural Nutrition and Physical Activity as "*Sedentary behaviours during pregnancy: a systematic review*", by Caterina Fazzi (Student and author of declaration), David H Saunders (Supervisor), Kathryn Linton, Jane E Norman (Supervisor), Rebecca M Reynolds (Supervisor). This study was conceived by all of the authors. I carried out all aspects of the review and wrote the manuscript.

The work presented in Chapter IV was previously published in the Scandinavian Journal of Medicine & Sciences in Sports as "*Activity behaviors in lean and morbidly obese pregnant women*", by Caterina Fazzi (Student and author of declaration), Nor Mohd-Shukri, Fiona C Denison, David H Saunders (Supervisor), Jane E Norman (Supervisor), Rebecca M Reynolds (Supervisor). This study was conceived by all of the authors. I conducted the calculations, developed the analyses, and wrote the manuscript.

No part of the work described in this thesis has been previously accepted for or is currently being submitted for another degree or professional qualification.

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Dedication

To my parents, María Eugenia and Luis.

For your unconditional love, respect and support. Thanks for teaching me to work hard and persevere to achieve my dreams.

A mis padres María Eugenia y Luis.

Por su amor incondicional, respeto y apoyo. Gracias por enseñarme a trabajar duro y perseverar para cumplir mis sueños.

Publications, Presentations and Posters

Publications

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Fazzi C, Mohd-Shukri N, Denison FC, Saunders DH, Norman JE, Reynolds RM. Activity behaviors in lean and morbidly obese pregnant women. Scand J Med Sci Sports. 2018 May 17. doi: 10.1111/sms.13219.

Oral Presentations

International Conference on Movement and Nutrition in Health and Disease, "Sedentary Behaviours during Pregnancy: A Systematic Review", July 2016, Regensburg, Germany.

International Conference on Movement and Nutrition in Health and Disease, "Activity Behaviours in Lean and Morbidly Obese Pregnant Women", June-July 2017, Regensburg, Germany.

Poster Presentations

The Scottish Physical Activity Research Connections (SPARC), poster: "Sedentary Behaviours during Pregnancy: A Systematic Review", Edinburgh, October 2016. Gained the 3rd Prize.

International Society of Behavioral Nutrition and Physical Activity (ISBNPA) Annual Meeting, poster: “Activity Behaviours in Lean and Morbidly Obese Pregnant Women”, Victoria, Canada, June 2017.

The Scientific Symposium on targeting inflammation to improve reproductive health across the lifecourse (SRI), poster: “Sedentary Behaviours in Morbidly Obese Pregnant Women”, Edinburgh, August 2017.

The Scottish Physical Activity Research Connections (SPARC), poster: “Designing a Physical Activity Intervention among Severely Obese Pregnant Women to Reduce Sedentary Behaviour by Promoting Active Sitting: Involving Patients in The Study Design”, Edinburgh, November 2017.

Edinburgh Sports and Exercise Medicine Conference, poster: “Options in Pregnancy to increase ActiveLy Sitting (OPALS) feasibility study”, Edinburgh, August 2018.

List of Abbreviations

a	adjusted
ACOG	American College of Obstetricians and Gynecologists
AEE	Active Energy Expenditure
AWAS	Australian Women's Activity Survey
BMI	Body Mass Index
BMR	Basal Metabolic Rate
CI	Confidence Interval
CRP	C-Reactive Protein
EBIP	Energy Balance in Pregnancy
FITT	Frequency, Intensity, Time, Type of exercise
GDM	Gestational Diabetes Mellitus
GLUT-4	Glucose Transporter type 4
GP	General Practitioner
GPAQ	Global Physical Activity Questionnaire
GWG	Gestational Weight Gain
HDL	High Density Lipoprotein
HIP	Hormones and Inflammation in Pregnancy
IOM	Institute of Medicine Guidelines
IPAQ	International Physical Activity Questionnaire

IRAS	Integrated Research Application System
Kcal	Kilocalorie
LDL	Low Density Lipoprotein
MET	Metabolic Equivalent
METs	Metabolic Equivalents
MPAQ	Madras Diabetes Research Foundation Physical Activity Questionnaire
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
OPALS	Options in Pregnancy to increase Actively Sitting
OR	Odds Ratio
PPAQ	Pregnancy Physical Activity Questionnaire
R&D	Research and Development
RMR	Resting Metabolic Rate
RPAQ	Recent Physical Activity Questionnaire
RR	Relative Risk
SBRN	Sedentary Behaviour Research Network
UK	United Kingdom
UPBEAT	UK Pregnancies Better Eating and Activity Trial
USA	United States of America
WHO	World Health Organization

List of Tables

	Page
Table 1. Summary of objective methods to assess energy expenditure and physical activity	46
Table 2. IOM Gestational weight gain recommendation guidelines	58
Table 3. Characteristics of included studies	137
Table 4. Time and proportion of time spent in sedentary behaviour	138
Table 5. Prevalence of sedentarism among pregnant women	140
Table 6. Associations between sedentary behaviour with maternal and infant health outcomes	145
Table 7. Comparisons between reviews	148
Table 8. Results Sedentary behaviour and physical activity questionnaire	208
Table 9. Frequency of interest in doing exercise 1, or exercise 2, or exercise 3	208
Table 10. OPALS feasibility questionnaire main results	233

List of Figures

	Page
Figure 1. Energy expenditure intensities	39
Figure 2. Energy balance	40
Figure 3. Related studies	157
Figure 4. Measurement instruments	162
Figure 5. Exercise 1	206
Figure 6. Exercise 2	206
Figure 7. Exercise 3	206
Figure 8. Exercise 4	206
Figure 9. Exercise 5	206
Figure 10. Exercise 6	206
Figure 11. Exercise 1	210
Figure 12. Exercise 2	211
Figure 13. Exercise 3	211
Figure 14. Exercise 4	212
Figure 15. Exercise 5	212
Figure 16. Exercise 6	213
Figure 17. Exercise guideline	215
Figure 18. Flow chart of recruitment process	232
Figure 19. Physical activity for pregnant women	244

Chapter I. Introduction

Chapter I. Introduction

1.1. Obesity

According to the World Health Organization (WHO) "overweight and obesity are defined as abnormal or excessive fat accumulation, which may impair health." (WHO, 2014). Regarding the adult population, rates of obesity are increasing all over the world. Worldwide among adult population (18 years or over), about 13% (11% of men and 15% of women) were obese in 2016, or about 650 million (WHO, 2017). In Scotland, 27.1% of adults were obese in 2013 and 37.5% were overweight, the highest prevalence among the United Kingdom (UK) countries (Scottish Government, 2014).

Body Mass Index (BMI) is the most used method to assess obesity status across large populations. BMI is obtained by dividing the weight in kilograms by the square of the height in meters. According to the WHO, overweight is defined as a BMI ≥ 25 Kg/m^2, obesity as BMI ≥ 30 Kg/m^2, and Class III, morbidly or severely obesity as BMI ≥ 40 Kg/m^2 (Seidell J & Flegal K, 1997). For pregnant women in the UK, as part of routine antenatal care, it is recommended that maternal height and weight should be assessed during the first booking appointment, usually between eight and 12 weeks of gestation, to calculate the BMI and determine if the pregnant woman is obese, based on the same categories used for adult non-pregnant population (NICE, 2008 (Last updated: January 2017)). However the assessment is not necessarily accurate as it might be self-reported. Indeed a systematic review and meta-analysis showed that women of reproductive age underestimated their weight (-0.94Kg mean difference, 95% Confidence Interval [CI] -1.17--0.71Kg; p<0.0001; 19 studies; 16,578 participants), and overestimated their height (0.36cm mean difference 95% CI 0.20-

0.51; p<0.0001;18 studies; 13,744 participants) when self-reported in contrast to direct measurement (Seijo M et al., 2018).

Among women of fertile age, obesity prevalence has also been increasing, as it has in the general population (Denison FC et al., 2014; Fitzsimons KJ & Modder J, 2010; Heslehurst N et al., 2008; Huda SS, Brodie LE, & Sattar N, 2010). In the United States of America (USA) among women aged 20 to 39 years, 34% were obese, and 8% were severely obese (Flegal K, Carroll M, Ogden C, & Curtin L, 2010).

1.1.1. Obesity and pregnancy

Among women delivering in Scotland in 2016, 22.2% were obese, a number that had increased by almost five points since 2011 (17.6%) (NHS Scotland, 2016). Whilst in 2009 in the UK around 2% were severely obese (BMI ≥40kg/m^2) (CMACE, 2010).

Obesity in pregnancy is associated with adverse outcomes for mother and offspring (Lisonkova S et al., 2018; Norman JE & Reynolds RM, 2011; Reynolds RM et al., 2013; Schummers L, Hutcheon JA, Bodnar LM, Lieberman E, & Himes KP, 2015; Scott-Pillai R, Spence D, Cardwell CR, Hunter A, & VA, 2013). The risks are even greater with morbidly obese women whom represent a very high risk group. In a cohort study conducted in Sweden including 1,024,471 women researchers comparing new-born outcomes to women of normal weight to those born to morbidly obese women, the latter were at higher risk of respiratory distress syndrome, bacterial sepsis, birth injury to the skeleton, hypoglycemia, birth injury to the peripheral nervous system, and convulsions. Additionally the risk of adverse neonatal outcomes was doubled among morbidly obese women compared with normal weight women, regardless of the mode of delivery (Blomberg M, 2014). In another study carried out in Scotland, the authors showed a strong association between high maternal BMI and greater risk of complications during pregnancy, higher costs to the health service, and larger numbers as well as duration of maternal admissions (Denison FC et al., 2014).

Interventions to increase energy expenditure are an option to control weight and gestational weight gain (GWG), but these are challenging in morbidly obese pregnant women (Denison FC, Weir Z, Carver H, Norman JE, & Reynolds RM, 2015). Overweight individuals expend considerably more calories than normal weight individuals doing the same exercise (McArdle W, Katch F, & Katch V, 2010). Obese pregnant women need more energy to move and have a higher metabolic cost than lean pregnant women. Further, their limbs are larger, so that the work of breathing and moving takes a greater effort, and peripheral motor efficiency is reduced (Mottola MF, 2013). The majority of interventions based on diet and increasing physical activity levels in obese pregnant women have been largely unsuccessful in preventing adverse pregnancy outcomes. There are different examples showing that researchers did not find differences after administering their interventions, certainly the reasons for failing are diverse and are not clear, however there are some things in common, such as including both, diet and exercise, not enough supervision on physical activity, and the lack of a physical activity specialist. The physical activity was more theoretical than practical, rather than giving them realistic and practical tools to increase women's physical activity. For example, in the The Limit Study (Dodd JM, 2014), a randomised trial carried out in Australia, which assessed 2,212 overweight or obese pregnant women between 10 and 20 weeks of gestation; 1,108 women were randomly assigned to the study group, which consisted in a dietary and lifestyle intervention along pregnancy delivered by a dietitian and a trained researcher or assistant. Physical activity advice was based mainly in encouraging women to increase walking and incidental activity. Babies born large for gestational age was the primary outcome. The other 1,104 women were assigned to the control group receiving standard care. The risk of delivering an infant weighing four kilograms or more was 18% lesser among the study group, compared to the control group. No other differences were observed on maternal or birth outcomes between groups (Dodd JM, 2014). Simiar outcomes were observed in a recently published randomised controlled trial (Kennelly MA et al., 2018), with overweight and obese women (25 Kg/m^2<BMI<40 Kg/m^2) using an intervention based on exercise and nutrition advice through an education session. The exercise advise focused on promoting the benefits and safety of physical activity in pregnancy, and was based on following the American College of Obstetricians and Gynecologists' (ACOG) guidance, which recommends doing 30 minutes of moderate-intensity exercise five to seven days per week, which can be divided into two bouts of 15 minutes or three bouts of 10 minutes (Artal R & O'Toole M, 2003). The education session was reinforced through a smartphone application, emails sent by the researchers, plus two more hospital appointemnts at 28 and 34 weeks of gestation. The primary outcome was to evaluate the effect of the exercise and nutrition on the incidence of Gestational Diabetes Mellitus (GDM). A two hour oral glucose tolerance test was performed to diagnose GDM, according to the International Association of Diabetes and Pregnancy Study Groups criteria (International Association of Diabetes and Pregnancy Study Groups, 2010).The authors did not observe significant differences on the incidence of GDM between the intervention (15.4%, n=241), and control group (14.1%, n=257) (Relative Risk [RR] 1.1; 95% CI 0.71-1.66; p=0.71) (Kennelly MA et al., 2018). Meanwhile, in the UK Pregnancies Better Eating and Active Trial (UPBEAT) Study (Poston L et al., 2015), involving obese pregnant women

(BMI>30 Kg/m^2), the authors aimed to study the effect of a behavioural intervention which included nutritional and physical activity advice in the incidence of GDM as the primary outcome. The intervention included one first individual interview with a health trainer, followed by eight group or individual one hour sessions leaded by the health trainer for eight weeks. The sessions focused mostly on behavioural change. Participants also received a handbook, including a safe exercise plan, a pedometer and a log book to record their goals. For the diagnosis of GDM used an oral glucose tolerance test, and by criteria from the International Association of Diabetes in Pregnancy Study Groups (International Association of Diabetes and Pregnancy Study Groups, 2010). No significant differences were found on the incidence of GDM between the intervention (25%, n=160) and the control group (26%, n=172) (RR 0.96; 95% CI 0.79–1.16; p=0.68) (Poston L et al., 2015). Similarly in the Healthy eating, Exercise and Lifestyle Trial study (Daly et al., 2017), involving obese pregnant women aiming to reduce the mean fasting plasma glucose levels by 6.9 mg/dL at 24-28 weeks of gestation (primary outcome) among women in the study group who took part in a medically supervised exercise intervention, compared with women in the control group. All participants received information on nutrition, as the usual care for obese pregnant women in Ireland. The control group received standard exercise information provided by the hospital, also as part of the routine antenatal care in Ireland for obese pregnant women. Meanwhile women in the study group were invited to take part in medically supervised exercise classes based on 10 minutes warm-up, 50-60 minutes of exercising, 15-20 minutes of resistance or weights, same time of aerobic training, and 10 minutes cold-down, three times per week along gestation and until six weeks after delivery. Additionally, those in the intervention group had the option to participate in a group in Facebook, to encourage sense of community between the participants, to enhance compliance and share healthy lifestyle counsel. Forty-three obese women in the intervention group and 43 in the control group attended to the glucose test at 24-28 weeks of gestation, the results showed no differences between the intervention and the control group in the mean fasting plasma glucose (control group 90.0±9.0mg/dL, n=43; intervention group 93.6±7.0 mg/dL, n=43; p=0.13). The authors observed no differences on the development of GDM between groups (control 48.8%; intervention 58.1%: p=0.51), however observed that the number of obese pregnant women in the study group that gained excessive gestational weight was significantly lower than the number of women in the control group, at 36 weeks of gestation (23.5% v/s 45.2% respectively; $p<0.05$) (Daly et al., 2017).

In a meta-analysis and health economic evaluation published in 2017 aiming to analyse the effect of different dietary and physical activity interventions during pregnancy on maternal and fetal outcomes including 74 randomised controlled trials, assessing 17,623 women, researchers looked at interventions involving diet, physical activity and both together, analysing the effect on pregnancy outcomes on mothers and babies. They found that interventions based on diet and physical activity in pregnancy reduced GWG by 0.70 Kg on average (33 studies; n=9,320; 95% CI-0.92--0.48Kg). After adjusting for maternal BMI, age, parity, ethnicity or underlying medical conditions the effect remained. Lifestyle interventions compared with others showed a reduction in the number of cesarean sections (Odds Ratio [OR] 0.91; 95% CI 0.83-0.99), but did not have an effect on pregnancy induced hypertension, preeclampsia, GDM or preterm birth. No significant effect was observed on offspring or maternal outcomes, leading to the conclusion that diet and lifestyle interventions were not cost-effective compare with standard care (Rogozinska E et al., 2017).

Most interventions aiming to help obese pregnant women to reduce the risks that obesity means for pregnancy focused on diet and physical activity or behavioural change, have failed in improving pregnancy outcomes. No intervention involved morbidly obese pregnant women in particular, none included exercise programs designed specifically for obese pregnant women, or involved a physical activity specialist. In addition, the advice was mostly theoretical rather than practical advice, and no studies offered supervision. All together this suggests that there is an opportunity to refine interventions to include more direct support for obese pregnant women to increase their physical activity, or to look at other ways such as aiming to reduce time spent sedentary, the focus of this thesis.

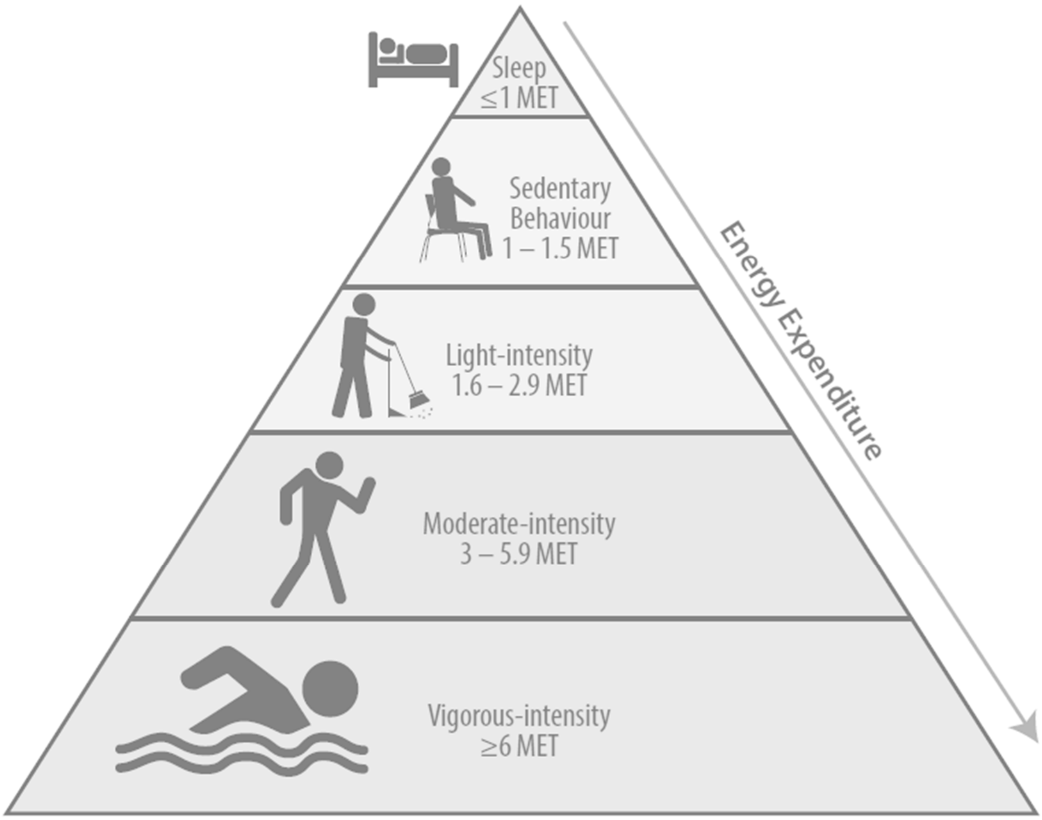
1.2. Energy expenditure

The total energy expended by the body (including all chemical reactions that expend energy) is called energy expenditure (McArdle W et al., 2010).

Energy expenditure has different components. The most important is basal metabolic rate (BMR) which is the minimum energy required for living (Keim NL, Blanton CA, & Kretsch MJ, 2004; McArdle W et al., 2010). Age, gender, body size, lifestyle and body composition are all determinants of the BMR (FAO/WHO/UNU, 2001). Measuring BMR is complex, as the subject has to be in a supine position, without eating for at least 12 hours, in the first hour in the morning, ideally not more than 30 minutes after awaking, but before standing up from a horizontal position, in a thermoneutral environment, in silence, darkness and no distractions. Therefore, usually what is measured is the resting metabolic rate (RMR), which estimates the energy expended when resting - this usually represents between 60% and 70% of the total energy expenditure (Keim NL et al., 2004).

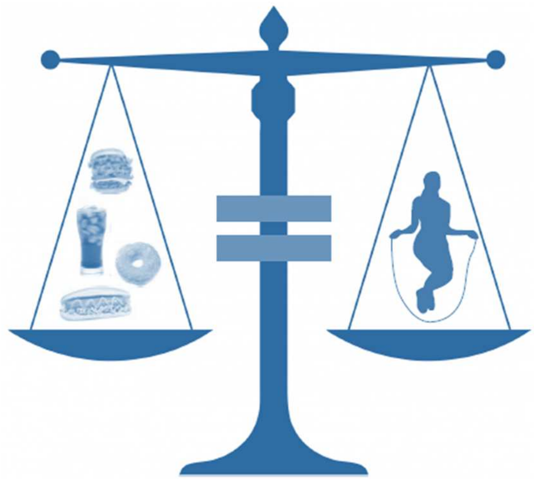
Energy expenditure is affected by multiple factors, such as climate (McArdle W et al., 2010), diet-induced thermogenesis, growth, and physical activity, (FAO/WHO/UNU, 2001; McArdle W et al., 2010). Physical activity includes all movements involving muscles that results in an energy expenditure over the resting metabolic rate (Caspersen CJ, Powell KE, & Christenson GM, 1985). The more intense the activity the more energy expended. The intensity is classified usually in four categories: sedentary, light, moderate and vigorous (**Figure 1**) (Ainsworth BE et al., 2011). The most used unit of measurement for energy expenditure is the metabolic equivalent (MET). One MET equates to the average energy expenditure or oxygen consumption of an adult in resting conditions (sitting or laying), which corresponds to 3.5 ml of oxygen per kilogram per minute, or 250 ml of oxygen per minute, or one kcal per kilogram per hour (McArdle W, Katch F, & Katch V, 2006).

Figure 1. Energy expenditure intensities.



Body weight is a result of the imbalance between the intake of energy content in the food eaten, and the body energy expenditure. This imbalance is commonly called energy balance. When the energy balance is positive, this means that the energy intake is more than the energy expended, which tends to increase the body weight. Contrarily, when the energy expenditure is higher than the energy consumption it is a negative energy balance, and the body weight tends to decrease (Hall KD et al., 2012).

Figure 2. Energy balance



Increasing the energy expenditure with obese people might be a useful way to help them to control or even to reduce their weight, but the easiest way for doing that means modifying their habitual activities for activities involving more intensity, or by replacing sedentary activities with light intensity activities (Hamilton MT, Healy GN, Dunstan DW, Zderic TW, & Owen N, 2008). However modifying severely obese population behaviour might not be an easy task, although the evidence that has shown that overweight subjects expend considerably more energy than average weight subjects in the same exercise (McArdle W et al., 2010).

1.2.1. Energy expenditure and physical activity assessment methods

Assessing energy expenditure accurately is not simple, therefore choosing the method is the most important decision to make (Ndahimana D & Kim E, 2017). There are many alternatives to assess energy expenditure, but most methodologies can be categorised into two main groups, objective and non-objective methods.

1.2.1.1. Objective methods

There are many different alternatives of objective devices to assess energy expenditure, some of which are described below. All options offer advantages and disadvantages, therefore the choice of the most appropriate for the study will depend on the aim, the budget and the population size (Adamakis M, Zounhia K, Karteroliotis K, & Koskolou M, 2016; Hills AP, Mokhtar N, & Byrne NM, 2014; Ndahimana D & Kim E, 2017; Troiano RP, 2009).

Energy expenditure is mostly explained by the activities that humans perform in their daily life, and human behaviour can be multidimensional and complex, therefore precise quantification can be difficult (Hills AP et al., 2014).

In free living conditions, doubly labelled water excretion is considered the most precise and accurate method to assess total energy expenditure, considered as the "Gold Standard", it is safe, non-invasive and does not cause discomfort to participants, and in addition it can be administered to different kind of population, including vulnerable subjects such as pregnant women and young children. The only disadvantage of the doubly labelled water method is that it provides data only on the total energy expenditure, but does not report data on the intensity, duration or type of activity performed to expend that energy. Doubly labelled water uses stable isotopes to calculate total energy expenditure. The isotopes are put in a glass of water, which is drunk by the subject, then they are tracked when they are eliminated from the body, by daily urine samples that are collected usually from seven to 14 days and analysed using an isotope ratio mass spectrometry. The rate of carbon dioxide production is equivalent to the difference between the elimination rates of isotopes, and that outcome reflects the average total energy expenditure.

However the doubly labelled water method is expensive, as the isotopes are expensive, plus requires sophisticated laboratory equipment for the analyses (Hills AP et al., 2014; Ndahimana D & Kim E, 2017; Schoeller DA, 1988; Schoeller DA & van Santen E, 1982).

Direct calorimetry is considered a precise method, as it directly measures heat or heat loss produced by the consumption of oxygen and production of carbon dioxide, as a result of combustion of substrates from food, but also measures heat loss. Indirect calorimetry is similar, and it is also considered a reliable method, but the technique is different; it estimates the energy expenditure based on the energy utilised by oxygen consumption, that is estimated as five kilocalories per litre of oxygen consumed (Hills AP et al., 2014). Nevertheless both forms of calorimetry are not frequently used to estimate free-living energy expenditure as multiple conditions are required to perform the measurements properly, it makes it too complex to keep subjects in their normal environment (Hills AP et al., 2014; Leonard WR, 2012).

Heart rate monitors are also objective devices used to assess energy expenditure, estimating oxygen consumption by heart rate, based on the strong correlation between oxygen consumption and heart rate. This correlation works well among activities of a certain intensity, usually ‘intermediate’ or over, but for light or sedentary activities, the relationship between heart rate and energy expenditure tends to fail. To solve that problem, researchers have designed a method which categorises the activities as resting or active, then the heart rate is assigned accordingly, minimising the error. There are several different heart rate monitors in the market, most of them are not too expensive, easy to wear, and non-invasive (Hills AP et al., 2014; Leonard WR, 2012).

Pedometers are also devices that can estimate energy expenditure, are widely used, as they are cheap and easy to wear, and lately their use has been disseminated widely to the general public to make people aware of their activity, and encourage them to become more active (Bravata DM et al., 2007; Kang M, Marshall SJ, Barreira TV, & Lee JO, 2009; Pal S, Cheng C, Egger G, Binns C, & Donovan R, 2009; Richardson CR et al., 2008; Tudor-Locke C, 2001). However it is important to highlight that the quality and reliability among the available pedometers differ considerably, therefore for research purposes it is recommended to look at the evidence, and choose those pedometers that have been tested and the quality has been proven (Hills AP et al., 2014; Tudor-Locke C et al., 2006). It has also been published that pedometers cannot be highly precise under some circumstances, therefore calibration is important to achieve reliable results. When the speed of walking is too low the number of steps recorded might be imprecise, and other factors such as where the pedometer is worn might also make the measurements less precise. For example for individuals with a large waist circumference pedometers may rotate if they wear it on the waist, which will give inaccurate data. Height and length of legs might also affect the performance of the pedometer, and it also has to be considered that some people may manipulate the device, particularly if the intention is to increase the number of steps (Hills AP et al., 2014; Tudor-Locke C & Lutes L, 2009). Finally, pedometers are obviously limited to count steps, therefore any activity other than walking or running are not involved in the measures (Hills AP et al., 2014).

Accelerometers are an objective and non-invasive appraisal method to assess energy expenditure, which offer a better way to assess energy expenditure, compared with heart rate monitors and pedometers, since they are handy, cause minimal discomfort, and more importantly, are accurate and reliable (Crouter SE, Clowers KG, & Bassett DRJr, 2006; Hills AP et al., 2014). Additionally, they are small and can register data uninterruptedly over long periods of time (days or weeks) (Hills AP et al., 2014). Accelerometers have been shown to be able to assess sedentary behaviour and physical activity with high precision and accuracy (Hills AP et al., 2014). Accelerometers are piezoelectric devices which transmit an electrical signal that is then converted to produce an indication of movement per unit time, typically counts per minute (Chen KY & Bassett DRJr, 2005). Therefore, counts can be defined as an indication of human movement in relation to different planes, gravitational forces, magnitude and duration of the sensed acceleration, but not linked to any subject characteristic. There are different kind of accelerometers, some accelerometers can detect acceleration in one plane (uni-axial), others in two planes (bi-axial), and some in three orthogonal planes (tri-axial), representing all directions. For instance the accelerometer employed in this thesis was the Actical (Mini Mitter Company, Inc., USA) which assesses movement in all directions but is most sensitive in the vertical plane, whilst the ActiGraph wGT3X-BT (Actigraph LLC, Pensacola, FL) is uni-axial assessing vertical deceleration and acceleration. Bi-axial accelerometers also assess vertical acceleration and deceleration. Tri-axial accelerometers, such as the RT6 (Stayhealthy Inc., Monrovia, CA), and the Personal Activity Monitor PAM AM300 (PAMB. V. Doorwerth, Netherlands) assess movement in three planes, providing theoretically a better representation of real movement (Chen KY & Bassett DRJr, 2005; Hills AP et al., 2014).

The most important advantage of the use of accelerometers is that they can calculate time spent in activities of different intensities. However there is no agreement on the cut-points for each intensity, making it difficult to compare between results reported by different studies. On the other hand, standard cut-off points might be not representative for different subjects performing the same activity (Lopes VP, Magalhaes P, Bragada J, & Vasques C, 2009). For instance, when we compare two people walking, but one is obese and the other is lean, the obese will probably expend more energy than the lean walking exactly the same distance, however the accelerometers will register no difference between subjects. Similarly accelerometers are limited in identifying upper body work, for instance walking carrying a load does not expend the same energy as walking without carrying anything, however the accelerometer will not make any difference in the register, although the effort will not be the same, neither the energy expended. Accelerometers cannot identify inclination of the surfaces, therefore the estimation of the energy expended walking in a flat surface will be just the same as walking up a slope, however more energy would be expended going up the hill. Accelerometers do not register efforts if there is no transference of the centre of gravity; this is a reason why accelerometers are unable to report static exercise. For instance, if I pull an elastic band with one of my legs whilst sitting, the accelerometer will not register the work according to the real intensity, because the centre of gravity does not move (Al-Eisa E, Alghadir AH, & Iqbal ZA, 2016; Hills AP et al., 2014). It is also important to highlight that accelerometers are inaccurate when assessing light intensity and sedentary activities, compared to other intensity activities, due to the low sensitivity (Bouten CV, Koekkoek KT, Verduin M, Kodde R, & Janssen JD, 1997; Calabro MA, Lee JM, Saint-Maurice PF, Yoo H, & Welk GJ, 2014; Hills AP et al., 2014).

Table 1. Summary of objective methods to assess energy expenditure and physical activity.

Objective appraisal methods	Advantages	Disadvantages
Doubly labelled water	- Very reliable - Non-invasive - No discomfort - Can be used in free-living conditions	- Provides data only on total energy expenditure - Expensive - A sophisticated laboratory is required for analysis
Direct calorimetry	- Very reliable	- Cannot be used in free-living conditions
Indirect calorimetry	- Reliable	- Cannot be used in free-living conditions
Heart rate monitors	- Inexpensive - Can be used in free-living conditions - Easy to wear - Non-invasive	- Not accurate for low-intensity activities
Pedometers	- Inexpensive - Non-invasive - No discomfort - Can be used in free-living conditions - Easy to wear - Some might be accurate	- Not reliable (can be manipulated) - Less precise under some circumstances - Limited to walking activities (only count steps)
Accelerometers	- Accurate - Can be used in free-living conditions - Non-invasive - No discomfort - Reliable	- Inaccurate under some circumstances (i.e. light activities, sitting activities, etc.)

1.2.1.2. Non-objective methods

Non-objective appraisal methods are methods which assess energy expenditure using indirect approaches. Usually, when researchers need to conduct studies with a large sample size, they are forced to use non-objective instruments, such as self-reported questionnaires, interviews, activity diaries and direct observation. Non-objective methods are usually less reliable, non-invasive, and inexpensive compared to objective methods (Hills AP et al., 2014). Unfortunately, self-reported information may be subject to recall bias, limited validity, and inaccuracy, and based on the evidence there is a lack of support regarding the reliability of questionnaires assessing physical activity in general (Lee PH, Macfarlane DJ, Lam TH, & Stewart SM, 2011; Phillips CM, Dillon CB, & Perry IJ, 2017).

Activity diaries might be considered a good method to assess energy expenditure, considering the low cost, and the fact that they can provide large and detailed data of the activity performed during a day. Thus using a 24 hours timeframe it is possible to estimate the energy expended in the day. The intensity is usually assigned using the Compendium of Physical Activities (Ainsworth BE et al., 2011), which is largely used, and includes most of physical activities. However activity diaries have a poor correlation with objective methods, besides they involve a huge burden for the participants, as they are required to complete it accurately every day, recalling every single activity (Hills AP et al., 2014; Vanroy C et al., 2014).

Questionnaires are the most widely used method to estimate energy expenditure, probably due to the affordable cost, that they are non-invasive, and are usually easy to administer. This is despite that they have been shown to demonstrate low compliance and validity, as they are based on retrospective information, and depend on participants' honesty (Hills AP et al., 2014; Vanroy C et al., 2014). Recall questionnaires are usually longer and detailed, providing more data, such as duration, frequency, and intensity of the activities, allowing researchers to estimate energy expenditure (Hills AP et al., 2014; Vanroy C et al., 2014). In order to minimise intentional or unintentional misreporting of physical activity, the recommendation is to add objective assessments to the self-reported questionnaires (Hills AP et al., 2014). The most used physical activity questionnaires are the International Physical Activity Questionnaire (IPAQ)(Craig CL et al., 2003), and the Global Physical Activity Questionnaire (GPAQ) (Bull FC, Maslin TS, & Armstrong T, 2009). Reliability and validity have been demonstrated for both methods, in different cultural settings (Al-Eisa E et al., 2016).

1.2.1.3. Methods to assess energy expenditure and physical activity in obese people.

Most of studies assessing physical activity and energy expenditure among obese people use accelerometers (Tudor-Locke C, Brashear MM, Johnson WD, & Katzmarzyk PT, 2010), probably because these are relatively affordable, and as self-reported methods tend to overestimate the results, based on different studies, accelerometers are more accurate and reliable (Al-Eisa E et al., 2016; Bell JA et al., 2015; Palta P et al., 2015). One review focused on assessing physical activity among obese subjects, recommended the use of two devices in combination in order to improve the accuracy of the measurements during daily living activities (Al-Eisa E et al., 2016). In another study, the researchers suggested to be careful when using accelerometers that have been validated with normal weight populations, when assessing moderate to vigorous physical activity in overweight and obese people, as usually both intensities of activity are based on metabolic equivalents (METs) cut-points, which might be inaccurate for obese or overweight subjects under higher intensity, as obesity is linked to a reduced cardiorespiratory and metabolic capacity (Innerd P, Harrison R, & Coulson M, 2018). Similarly, in a study measuring total daily energy expenditure among 14 obese women, to compare the accuracy of heart rate monitors, and physical activity questionnaires, in contrast to doubly labelled water, researchers observed that compared with doubly labelled water, heart rate monitors and questionnaire assessed accurately. However for obese participants the calculation of energy expended had to be modified according to the body composition, in order to avoid overestimation caused by the excess fat mass (as fat mass is less metabolically active than free fat mass). In fact basal metabolic rate does not increase in the direction and proportion as weight (Racette SB, Schoeller DA, & Kushner RF, 1995).

1.2.1.4. Methods to assess energy expenditure among obese pregnant women

Not much has been published regarding methods to assess physical activity among obese pregnant women. Until 2012, no questionnaire had been specifically validated with obese pregnant women (Chandonnet N, Saey D, Almeras N, & Marc I, 2012).

The Pregnancy Physical Activity Questionnaire (PPAQ) was validated among a sample of 54 normal-weight pregnant women against the Manufacturing Technology, Inc. Actigraph in 2004 (Chasan-Taber L et al., 2004), but the reliability among obese pregnant women was not proved. However a French version of the PPAQ was tested against the GT1M Actigraph activity monitor, with a sample of 49 obese pregnant women. The outcomes showed that to assess physical activity of different types and intensities with obese pregnant women, the PPAQ was reliable and "moderately accurate" in words of the authors (Spearman correlation coefficient 0.50 for total activity). Although the authors acknowledged that the data obtained by the PPAQ might be somehow inaccurate, as obese pregnant women might have reported doing more activities than they really performed. The correlation coefficients might also have been affected by the time difference of the administration of the questionnaire and the accelerometer, as participants had to answer the questionnaire regarding the past three months. However the authors suggested that the high proportion of time spent in light and in sedentary activities among obese pregnant women might be mostly the cause of the low correlation coefficients, considering the limited capacity of the Actigraph to identify upper body movements. In order to avoid that, the use of diaries in addition to questionnaires and accelerometers might be helpful. The authors concluded that to assess physical activity of different types and intensities with obese pregnant women, the use of questionnaires plus accelerometers should be employed for an accurate and detailed measurement (Chandonnet N et al., 2012). Of note – this is what we did in Chapter IV.

One study compared self-reported methods with accelerometers. Using the GT1M Actigraph accelerometer, the Australian Women's Activity Survey (AWAS), and the Recent Physical Activity Questionnaire (RPAQ), including 59 women with BMI over 25 Kg/m^2, of whom 48% were obese. The authors found that compared with the accelerometer, the AWAS overestimated light activity and time spent in moderate to vigorous physical activities. Meanwhile the RPAQ also overestimated the time spent in moderate to vigorous activities, compared with the accelerometer, but not as much as the AWAS, whilst underestimated light activities. Both questionnaires overestimated total activity (Bell R et al., 2013), which is consistent which has been described before (Al-Eisa E et al., 2016; Bell JA et al., 2015; Palta P et al., 2015). Researchers recommended to be careful when assessing physical activity with overweight or obese pregnant women using the AWAS or the RPAQ, meanwhile they considered that the use of accelerometer was acceptable and feasible, suggesting that whether possible use objective methods rather than self-reported, unless better questionnaires with verifiable validity are offered (Bell R et al., 2013).

1.3. Physical activity in obese pregnant women

1.3.1. Patterns of physical activity among obese pregnant women

Around the world, pregnant women are less active than non-pregnant women (Amezcua C et al., 2013; Bacchi E et al., 2016; Coll C et al., 2016; Daly N et al., 2016; Domingues MR & Barros AJ, 2007; Evenson KR, Savitz D, & Huston S, 2004; Evenson KR & Wen F, 2010; Gaston A & Cramp A, 2011; Nascimento SL, Surita FG, Godoy AC, Kasawara KT, & Morais SS, 2015), and most pregnant women do not accomplish the recommended physical activity levels (Amezcua C et al., 2013; Daly N et al., 2016; Evenson KR et al., 2004; Evenson KR & Wen F, 2010; Nascimento SL et al., 2015; Walsh J M, McGowan C, Byrne J, & McAuliffe FM, 2011). Researchers have shown that physical activity volume is even lower among overweight and obese pregnant women compared with normal-weight (Bacchi E et al., 2016).

During pregnancy, it has been observed that the physical activity amount usually declines as pregnancy progresses (Daly N et al., 2016; Domingues MR & Barros AJ, 2007; Gaston A & Cramp A, 2011; Liu J et al., 2011; Renault K et al., 2012; Rousham EK, Clarke PE, & Gross H, 2006; Ruifrok AE et al., 2014; Sui Z & Dodd JM, 2013), particularly among overweight and obese pregnant women (Daly N et al., 2016; Renault K, Norgaard K, Andreasen KR, Secher NJ, & Nilas L, 2010; Renault K et al., 2012). For instance in the study conducted by Renault in 2010, it was observed that obese pregnant women (n=130) reduced the number of daily steps from 7,446 (5,653-9,722) on average in mid pregnancy (18-22 weeks of gestation), to 4,626 (3,230-6,453) steps in late pregnancy (38-38 weeks of gestation), a difference that was statistically significant ($p<0.05$) (Renault K et al., 2010). The same author, observed in another study that physical activity declined significantly after week 29 of gestation ($p<0.0001$) among obese pregnant women ($n=22$) (Renault K et al., 2012). Similarly, an inverse association between BMI and physical activity levels in pregnancy was reported in one study with a sample of 1,175 pregnant women using the Paffenbarger Physical Activity Questionnaire to measure physical activity. The BMI increased as “any recommended” and “any moderate-vigorous” physical activity decreased (Amezcua-Prieto C et al., 2015).

1.3.2. Recommended physical activity for obese pregnant women

According to the American College of Obstetricians and Gynecologists (ACOG) Committee Opinion (Seneviratne SN, McCowan LM, Cutfield WS, Derraik JG, & Hofman PL, 2014), physical activity is desirable and safe for pregnant women with no obstetric or medical complication or contraindication, and health care providers should encourage pregnant women to be active during pregnancy (ACOG, 2002). Similarly, in overweight and obese pregnant women physical activity has been shown to be safe, and no associations with adverse or perinatal outcomes for mother and foetus have been observed, such as low birthweight (defined as <2500g) or preterm delivery. Also, no adverse effects on maternal systolic or diastolic arterial blood pressure have been reported (Nascimento S, Surita F, Parpinelli M, Siani S, & Pinto e Silva J, 2011).

Most guidelines recommend aerobic activities as well as strengthening exercises, varying from two days to every day per week, from 15 up to 60 minutes, which can be increased according to some guidelines (Evenson KR et al., 2014).

In the UK, the National Health Service (NHS) website recommends pregnant women to exercise during pregnancy, it says that being fit and active will help to adapt to the changes and weight gain, and to deal with the delivery and to recover the shape after birth. They are very clear and insist in avoiding exercising toward exhaustion, clarifying that exercising does not need to be too intense to be beneficial, explaining that the right level of intensity, should let them hold a conversation, and feeling breathless is a sign of strenuous effort, which is not good. It is also clear that exercising is not dangerous for the baby. The recommendation for women who were inactive before pregnancy is to start gradually, preferably with aerobic exercises, such as running, swimming, cycling or walking, for no more than 15 minutes uninterrupted, for three times per week, to increase little by little the duration of the sessions to 30 minutes, four times per week and to keep exercising as long as they feel comfortable. They include some tips for exercising, such as to warm up before starting, and cool down afterwards, to drink plenty of water, and also a list of exercises to be avoided during pregnancy, such as to lie on the back for long time, mostly after 16 weeks of gestation, avoid sports which imply risk of falling, scuba diving, contact sports, and exercise in heights over 2,500 metres. The website also offers a list of exercises to be perform during pregnancy (NHS UK, last reviewed 2017). Similarly, in the National Institute for Health and Care Excellence (NICE) Guidelines for weight management before, during and after pregnancy, there is a special recommendation for women with a BMI of 30 Kg/m^2 or more. These guidelines are mostly targeted for health professionals (to give them advice as to what to say to pregnant women), and recommend them to advise obese pregnant women to be physically active, which might benefit both, mother and baby, which will not harm them or their babies. Specifically it is recommended that obese pregnant women should exercise at a moderate intensity for at least 30 minutes per day. The guidelines also suggest to give practical and specific advice to obese pregnant women in how to be more active during pregnancy, clarifying that recreational exercise is safe and beneficial, and the aim should be ‘just to be fit’, rather than ‘to achieve a great performance’. The guidelines explain that for women who have not exercised before it should be good to start with 15 minutes of continuous exercise, three times a week, to increase the time and the number of sessions gradually to 30 minutes every day, meanwhile those women who were active before getting pregnant, should maintain their activity, and there is no adverse effect. Finally, it is explained that for those women who feel that the proposed level of physical activity is difficult, health professionals have to explain them that it is important not to be inactive as far as possible, encouraging them to start walking and to incorporate physical activity to their daily lifestyle (NICE, 2010).

Maternal exercise should be prescribed using the FITT principle (Frequency, Intensity, Time (duration) and Type of exercise (Bulger S, 2010; Nascimento SL et al., 2015)), for all women, regardless of the nutritional status (Mottola MF, 2009). Since obese pregnant women may have functional limitations, well-designed exercise programs are crucial, as well as a thorough explanation on how to perform each exercise correctly (Ehrsam R, Hoerler-Koerner U, Stoffel S, Melges T, & Ainsworth B, 2009). It is recommended by different authors for obese pregnant women to engage in physical activity sessions with a frequency of at least three times a week, using a target heart rate of 102 to 124 beats per minute, for women from 20 to 29 years old, or 101 to 120 beats per minute, for women between 30 and 39 years old (Davenport MH, Charlesworth S, Vanderspank D, Sopper MM, & Mottola MF, 2008; Mottola MF, 2013). Nevertheless, most used guidelines for physical activity during pregnancy do not specify on physical activity particularly for obese pregnant women (Davies GAL, Wolfe LA, Mottola MF, & MacKinnon C, 2003; RCOG, 2006; WHO, 2010), with the exception of the ACOG which recommends for obese pregnant women to take part in an exercise program along pregnancy (ACOG, 2002, 2013).

In general, pregnant women are counselled to avoid sports involving too much contact, activities that may cause falls or trauma, scuba diving, athletic competition, exercises in the supine posture, activities which mean persistent standing, and the exposure to environments of high altitude (over 5,250 feet, or 1,600 m), or high heat and humidity (Hinman SK, Smith KB, Quillen DM, & Smith MS, 2015; Mottola MF, 2016; NHS UK, last reviewed 2017).

1.3.3. Benefits of exercising during pregnancy

Several studies have shown that physical activity during pregnancy is beneficial for mothers and offspring.

1.3.3.1. Preterm birth

It has been largely reported that women who were active during pregnancy are less likely to have a preterm birth. In a recently published systematic review and meta-analysis of randomised controlled trials, the authors observed an inverse association between leisure time physical activity and the risk of preterm birth among 11 cohort studies, including 81,595 participants (OR 0.80; 95% CI 0.70–0.91) (da Silva SG, Ricardo LI, Evenson KR, & Hallal PC, 2017). Similarly, in a longitudinal study which was not included in the mentioned systematic review, with a sample of 1,713 women, the authors observed that lower rates of preterm births (12.2%) were associated with women categorised as long-term physically active compared to women categorised as not physically active (18.7%), which persisted after adjusting for covariates (adjusted [a] OR 0.55; 95% CI 0.33–0.91) (Vamos CA et al., 2015).

1.3.3.2. Gestational diabetes mellitus (GDM)

Another beneficial association of physical activity during pregnancy has been observed for the risk of developing GDM. In a meta-analysis developed in 2011 including five papers with 4,401 pregnant women (361 cases of GDM), exercise was significantly protective against GDM (OR 0.76; 95% CI 0.70–0.83) (Tobias DK, Zhang C, Van Dam RM, Bowers K, & Hu FB, 2011). Similarly, in a randomised controlled trial performed in Spain, in which the primary outcome was diagnosis of GDM, including 342 pregnant women, researchers compared the effect of an exercise program, for the study group, and standard care for the control group, finding that the prevalence of GDM was lower among the study group compared with the control group (OR 0.10; 95% CI 0.01–0.80). The authors followed the National Diabetes Data Group criteria to diagnose GDM. They concluded that exercising during pregnancy preserved glucose tolerance, which consequently reduced the prevalence of GDM (Cordero Y, Mottola MF, Vargas J, Blanco M, & Barakat R, 2015). Likewise, in a randomised controlled trial including overweight and obese pregnant women (BMI>24 Kg/m^2) women who were randomly assigned to the study participated in an exercise intervention involving regular supervised stationary cycling (n=132). Women randomised to the control group received standard care (n=133). The exercise sessions were carried out in a hospital, on alternate days, including five minutes of warm-up, and based on interval cycling at different intensities, starting at 55-65% of the maximum heart rate predicted by age, including repetitions of 30 seconds or one minute intervals at 75-85% of the maximum heart rate predicted by age, to finish every session with five minute cool down of easy cycling. In the beginning, women trained in the lowest range of the planned intensity, which was increased progressively. The duration of the sessions also increased progressively, by adding five minutes until reach 45-60 minutes. The primary outcome was the incidence of GDM. The results showed a reduction of 45.8% in the incidence of GDM among women in the study group. Additionally, the incidence of GDM was significantly lower (22%) among women in the study group than the incidence in the control group (40.6%) (OR 0.412; 95% CI 0.240-0.705; p<0.001) (Wang C et al., 2017).

1.3.3.3. Gestational weight gain (GWG)

Another beneficial effect of physical activity, which has been observed in different publications, is on the management of GWG during pregnancy. In a meta-analysis published in 2016, among the randomised controlled trials, including 1,605 women in the control groups and 1,598 in the exercise groups, the researchers observed that women who exercised during pregnancy gained on average -1.11 Kg less weight than the inactive pregnant women (difference in standard error -1.53; -0.69). No heterogeneity was observed through the trials (I^2=0%; p=0.868). Meanwhile among the cohort studies, most studies classified participants as exceeding or not the recommended weight gain, based on the Institute of Medicine Guidelines (IOM, 2009), see **Table 2**. Compared with inactive women, active women showed 18% lower risk of exceeding GWG recommendations (OR 0.82; 95% CI 0.68–0.99) (da Silva SG et al., 2017). Similarly, in the UPBEAT study (data not included in the meta-analysis) GWG was assessed as a secondary outcome. After the intervention, obese pregnant women in the study group gained significantly less weight (n=526, 7.19 Kg ±4.6) than obese pregnant women in the control group (n=567, 7.76 Kg ±4.6) (mean difference –0.55; 95% CI –1.08–0.02; p=0.041) (Poston L et al., 2015). In another study carried out in the USA, published in 2014, the researchers studied 856 pregnant women, 46% gained more weight during pregnancy than the recommended on the

Institute of Medicine Guidelines (IOM, 2009). Active women, who exercised at least three times a week during pregnancy had a lower odds of gaining excessive gestational weight (aOR 0.43; 95% CI 0.24–0.78), and were more likely to gain the recommended weight (32.7%) than those who reported exercising less than three times a week (18.7%) (Harris ST, Liu J, Wilcox S, Moran R, & Gallagher A, 2015). In the Limit randomised trial (also not included in the meta-analysis), including overweight and obese pregnant women, the authors conducted an antenatal lifestyle advice, which included the promotion of physical activity during pregnancy. No differences were observed between prticipants in the study group and participants in the control group on GWG, which was a secondary outcome of the study. Overweight and obese pregnant women in the intervention group (n=1,075) gained 9.44 Kg ±5.74, meanwhile in the control group (n=1,067), women gained on average 9.55 Kg ±5.77 (adjusted mean difference -0.04, 95% CI -0.55-0.48; p=0.89) (Dodd J et al., 2014).

Table 2. Institute of Medicine gestational weight gain recommendations: 2009 guidelines (IOM, 2009)

Pre-pregnancy Weight Status (Body Mass Index; Kg/m²)	Gestational Weight Gain lbs	Kg
Underweight (<18.5)	28-40	12.7-18.2
Normal weight (18.5-24.9)	25-35	11.3-15.9
Overweight (25.0-29.9)	15-25	6.8–11.3
Obese (≥30.0)	11-20	5–9.1

1.3.3.4. Pregnancy induced hypertension and preeclampsia

Pregnancy-induced hypertension risk may also be reduced by physical activity. In a randomised controlled trial with pregnant women using an exercise intervention to study the effect on gestational hypertension and macrosomia as the primary outcomes. The control group (n=383) received standard care, whilst the study group (n=382) exercised three times per week between 50 to 55 minutes, including toning, pelvic floor exercises, light resistance, and aerobic dance. Women in the control group had three times more probability of developing pregnancy-induced hypertension than women in the study group (OR 2.96; 95% CI 1.29–6.81; p=0.01). After stratifying for BMI, the incidence of gestational hypertension was significantly lower among the study group (p=0.02), the proportion of excessive GWG was also lower among the study group (p=0.01), the incidence of GDM was significantly lower among women in the study group (p=0.03), and the rate of macrosomic babies was also significantly lower among mothers in the study group compared with mothers in the control group (p=0.03). Compliance in the study group reached more than 80% (Barakat R et al., 2016). In a case-control study published in 1989, the researchers looked at the relation between the risk of developing pre-eclampsia and gestational hypertension, and leisure time physical activity during the first 20 weeks of gestation. Included in the study were 505 controls, and 172 women who developed pre-eclampsia. They found an association between leisure time physical activity during the first 20 weeks of gestation and a reduction in the risk of pre-eclampsia (aRR 0.67; 95% CI 0.46-0.96) and gestational hypertension (aRR 0.75; 95% CI 0.54-1.05) (Marcoux S, Brisson J, & Fabia J, 1989). Similarly, in a case-control study published in 2016, including 258 women who developed preeclampsia, 233 developed gestational hypertension, and 182 normotensive, after adjusting for BMI the researchers found a reduced risk of preeclampsia associated with increasing the levels of leisure time physical activity in minutes per week (OR 0.99; 95% CI 0.98-1.00). It was also observed that increasing the amount of time spent active per day was linked to a reduction in the risk of developing preeclampsia (aOR 0.58; 95% CI 0.36-0.95) (Spracklen CN, Ryckman KK, Triche EW, & Saftlas AF, 2016).

1.3.3.5. Birthweight

Birthweight has also been studied as an outcome that may be affected by physical activity during pregnancy. In a cohort study assessing 1,913 pregnant women, the researchers estimated energy expenditure for total activity, sports and exercise, and vigorous intensity activities, using the PPAQ in all trimesters of pregnancy. Higher levels of sports and exercise during the first trimester of pregnancy was associated with delivering lower birthweight offspring. They observed a reduction of 2.5g in the baby per each increased metabolic equivalent per hour a week expended in sports and exercise activities. No association was observed between energy expenditure and small for gestational age, based on the Canadian reference defined as birthweight lesser than the tenth percentile (Kramer MS et al., 2001), after adjusting for sex and gestational age (Bisson M et al., 2017). In a randomised controlled trial the authors studied the association between exercising during pregnancy and delivering a macrosomic baby, defined as weighing 4,000g or more. Pregnant women with singleton and uncomplicated pregnancies were included. 382 participants were randomised into an exercise group, and 383 into the control group. Women in the exercise group were trained in sessions of 50 to 55 minutes, three times per week. The exercise intervention lasted since first trimester to week 38 or 39 of gestation, whilst women in the control group received standard care. The authors found that giving birth to a macrosomic baby was 2.5 times more likely among women in the control group, who did not exercise during pregnancy, compared with women in the intervention group (OR 2.53; 95% CI 1.03–6.20; p=0.04) (Barakat R et al., 2016). In a randomised controlled trial aiming to look at the effect of maternal physical activity during pregnancy on abnormal fetal growth, including 166 pregnant women in the study group, who exercised three times per week at submaximal intensity along gestation, and 168 women in the control group, who received standard care, researchers observed a significantly lower number of macrosomic offspring among women in the study group, compared with women in the control group (6.0% vs 12.5%) (p=0.048) (Tomic V et al., 2013). In other randomised controlled trial involving overweight and obese pregnant women researchers used a home-based stationary bicycles approach. The primary outcome was the infant birthweight. Women in the study group (n=38) were asked to take part in the exercise intervention from week 20 to week 35 of gestation, with a frequency of three to five sessions per week; participants were visited by an exercise physiologist at home at baseline, received written instructions regarding weekly frequency and duration. They also received a heart rate monitor which was meant to be worn during the exercise sessions and was used to follow the prescribed heart rate targets and to maintain the exercise at the requested intensity (40 to 59% of the heart rate reserve). Women in the control group (n=37) did not receive a heart rate monitor nor exercise advice. Both groups received standard antenatal care. No differences were found between groups on infant birthweight, GWG, quality of life in any dimension, pregnancy outcomes or maternal body composition after delivery. Compared with the control group, a significant improvement on aerobic fitness was observed among the study group (p =0.019). Low compliance with the intervention was observed, 33% of the exercise sessions were accomplished (Seneviratne SN et al., 2016).

1.3.3.6. Mode of delivery

Additionally, active pregnant women have shown lowered rates of cesarean section, and instrumental deliveries. In a randomised controlled trial, the researchers studied the effect of a supervised physical activity intervention during pregnancy based on exercises of moderate intensity on the type of delivery and pregnancy outcomes. They assessed 290 pregnant women (138 in the study group, and 152 in the control group), and found a higher number of instrumental deliveries in the control group (19.1%, n=29), compared with the study group (11.6%, n=16) (p=0.03), the same was observed for cesarean sections, the number was lower among women in the exercise group (15.9%, n=22) compared with women in the control group (23%, n=35) (p = 0.03) (RR 0.69; 95% CI=0.42-0.82). No differences were observed in the offspring health variables such as Apgar scores and birth weight or for other pregnancy outcomes such as mean blood pressure, and glucose results in an Oral Glucose Tolerance Test (Barakat R, Pelaez M, Lopez C, Montejo R, & Coteron J, 2012). A lesser number of instrumental deliveries was also observed among women who were more active during pregnancy, in a prospective cohort study (aOR 1.72; 95% CI 1.05-2.9). The sample comprised 144 pregnant women classified as low active, and 126 pregnant women classified as highly active, based on the accelerometer data (Morgan KL et al., 2014).

1.3.3.7. Offspring adiposity

It was observed in another study including 263 pregnant women, that there is an increased risk of delivering a baby with adiposity over the 90th centile (15.59%, n=41) among women reporting lowering their physical activity levels between week 15 and 20 of gestation (aOR 1.62; 95% CI 1.06-2.47) (Norris T et al., 2017). Similarly, in a study comparing 20 pregnant women who exercised regularly during pregnancy, and 20 who did not, the researchers observed that children born of mothers who exercised during pregnancy presented significantly less percentage of fat mass at birth (10.5% ± 0.9) compared with children whose mothers did not exercise during gestation (15.1% ±0.6) ($p<0.01$). Additionally, at five years old those children born to mothers who exercised during pregnancy showed significantly lesser values in the sum of five skin folds (37mm ±1), compared with children whose mothers did not exercise during gestation (44mm ±2) ($p<0.01$) (Clapp J F, 1996).

1.3.3.8. Others benefits of antenatal physical activity on maternal health outcomes

Importantly, the potential benefits of antenatal exercise for obese pregnant women on maternal and infant health outcomes, other than improving glucose tolerance (Ong MJ et al., 2009), insulin sensitivity (van Poppel MN et al., 2013), and managing weight gain (Claesson IM et al., 2008; Oteng-Ntim E, Varma R, Croker H, Poston L, & Doyle P, 2012), and all the ones that have been described above remain uncertain. Nonetheless, it is clear that no adverse effects have been found to date. Besides, it has been suggested that the prevalence of lower back pain is lesser among obese pregnant women who exercised, in contrast to women who did not exercise during pregnancy (Nascimento S et al., 2011). A significant reduction in C-reactive protein (CRP) levels (an indication of inflammation) was observed among obese women who participated in a physical activity intervention (Renault KM et al., 2017). Unfortunately most of studies aiming to study the effect of physical activity on pregnancy and birth outcomes for mothers and babies include normal-weight pregnant women (14 of the 23 mentioned above), some included only overweight and obese (BMI≥25 Kg/m^2) (five of the 23 cited above), and a few on obese pregnant women (BMI≥30 Kg/m^2), which might include morbidly obese (BMI≥40 Kg/m^2) (four of the 23 mentioned above included obese pregnant women exclusively, and one excluded morbidly obese), whilst no one included particularly morbidly obese pregnant women. All in all, more studies which are suitably designed, and adequately powered are required to confirm the benefits of physical activity during pregnancy for obese women, and morbidly obese women.

1.3.4. Adverse effects of exercise during pregnancy

In the last decades uncertainty has been reported regarding the safety of exercising during pregnancy in pregnancy outcomes, for babies and for mothers, mostly because of the lack of robust evidence about the risks of exercising during pregnancy. In fact, physical activity recommendations during pregnancy have changed drastically, based on the evidence, which has been improving (2018 Physical Activity Guidelines Advisory Committee, 2018; Evenson KR et al., 2014; Pivarnik JM et al., 2006). According to the recently published Physical Activity Guidelines Advisory Committee Scientific Report Back in 1985 the ACOG Technical Bulletin recommended pregnant women to keep their heart beats under 140 beats per minute, and to avoid exercising vigorously for longer than 15 minutes (Larsen JW Jr & Greendale K, 1985). Since then, recommendations for pregnant women on physical activity have changed significantly, nowadays most of the guidelines around the world recommend moderate-intensity physical activity during pregnancy for normal pregnancies, as exercising at a moderate-intensity is safe and is thought to be beneficial for mothers and offspring (2018 Physical Activity Guidelines Advisory Committee, 2018; Evenson KR et al., 2014). For outcomes related to vigorous-intensity physical activity during pregnancy, there is a lack of robust evidence from well-designed studies. Therefore it is uncertain whether or not it is safe to exercise at a vigorous intensity during pregnancy (Evenson KR et al., 2014). A few adverse effects of exercise during pregnancy have been reported, mostly in relation to low birthweight or foetal growth and preterm birth, which are described as follows.

1.3.4.1. Low birthweight

Early in 1990 a study was designed to investigate the effect of a systematic aerobics and/or running program during late pregnancy on foetal growth. Offspring were classified into two groups, a control group (n=55) and the study group involving offspring whose mothers were aerobic dancers or recreational runners and who continued exercising at 50% of their pre-pregnancy level or above during pregnancy, and delivered at term (n=77). Exercise performance was assessed pre-pregnancy and daily throughout pregnancy. Birthweight among babies of mothers in the study group was significantly lower than birthweight of babies in the control group (-310g). The authors declared that 70% of the difference in birthweight might be explained by fat mass difference, as percentage of body fat mass was 5.0% lesser among babies in the study group compared to the control group, and fat mass was 220g lower in the study group compared with the control group (Clapp JF 3rd & Capeless EL, 1990). In a meta-analysis conducted in 2003, including 30 studies exploring the effect of exercise during pregnancy and birth weight, it was observed that pregnant women who exercised at a vigorous intensity until the third trimester of pregnancy had a higher risk of delivering babies weighing 200-400g less than women who did not exercise during pregnancy. The authors concluded that in general exercise during pregnancy does not considerably influence birth weight, unless pregnant women keep exercising vigorously towards the third trimester (Leet T & Flick L, 2003). Similarly, in a systematic review and meta-analysis of observational studies, the authors found that, after adjusting for confounders, five of the 37 studies exploring the association between birth weight and physical activity observed that birth weight significantly reduced as maternal activity increased (Bisson M, Lavoie-Guenette J, Tremblay A, & Marc I, 2016). In another systematic review and meta-analysis no association was observed between physical activity during pregnancy and small for gestational age, or low birthweight (da Silva SG et al., 2017). Finally, in a systematic review and meta-analysis of randomised controlled trials, the researchers observed that exercise interventions during pregnancy are apparently safe for the foetus and that are associated with a slight reduction in infants' birthweight within normal range. No differences were observed in gestational age at delivery between study and control groups (Sanabria-Martinez G et al., 2016).

1.3.4.2. Preterm birth

Inconsistencies have been found in the literature regarding whether exercise during pregnancy might be a risk factor for preterm birth.

One cohort study was found aiming to determine the association between physical activity and the risk of preterm birth. The study included low income pregnant women. The researchers reported higher odds of preterm delivery among women who climbed stairs more than 10 times per day (after adjusting for confounders) (OR 1.60; 95% CI 1.05-2.46; climbing >10 times/day n= 299, climbing ≤10 times/day n=851). Researchers also reported greater odds of preterm delivery among women who participated in intentional walking more than four days per week (OR 2.10; 95% CI 1.38-3.20; walking ≥4 days/week n=302, walking <4 days/week n=864). Contrarily, the authors reported a protective effect on preterm delivery of leisure-time exercise, involving more than 60 days in the first and second trimesters combined (OR 0.51; 95% CI 0.27-0.95) (Misra DP, Strobino DM, Stashinko EE, Nagey DA, & Nanda J, 1998). Similarly, another meta-analysis was carried out to study the association between working conditions and adverse pregnancy outcomes. This analysis included 160,988 women in 29 studies to assess the association of different physically occupational exposures. The authors found that physically demanding work was significantly associated with preterm birth (OR 1.22; 95% CI 1.16-1.29). Also prolonged standing was significantly associated with preterm birth (OR 1.26; 95% CI 1.13-1.40), shift and night work was also significantly associated with preterm birth (OR 1.24; 95% CI 1.06-1.46), and high cumulative work fatigue score was significantly associate with preterm birth (OR 1.63; 95% CI 1.33-1.98). No significant association was observed between long work hours and preterm birth (OR 1.03; 95% CI 0.92-1.16). The authors concluded that physically demanding work during pregnancy may significantly increase the risk of preterm birth (Mozurkewich EL, Luke B, Avni M, & Wolf FM, 2000). In a similar meta-analysis focused on the association of occupational physical activity and pregnancy outcomes, the authors looked at five most common occupational exposures (standing and heavy physical workload, prolonged working hours, lifting, and shift work). Thirty-five studies were identified with preterm delivery, however it was reported that the evidence was not sufficient to recommend avoiding the activities considered in the review (Bonzini M, Coggon D, & Palmer KT, 2007).

Contrarily, in more recently reviews, the findings show no risk of exercise during pregnancy and preterm birth. A systematic review and meta-analysis of randomised controlled trials was conducted, aiming to study the effects of exercise during pregnancy on the incidence of preterm delivery. Nine studies were included involving normal weight pregnant women, exercise interventions during pregnancy involving aerobic exercises sessions lasting between 35 to 90 minutes, three to four times per week. All together 2,059 pregnant women were included, 1,022 in the exercise group and 1,037 to the control group. No differences were found in the incidence of preterm birth (defined by the authors as <37 weeks of gestation) between women in the intervention group and women in the control group (4.5% vs 4.4% respectively; RR 1.01; 95% CI 0.68-1.50) (Di Mascio D, Magro-Malosso ER, Saccone G, Marhefka GD, & Berghella V, 2016). Similarly in another systematic review and meta-analysis analysing the relationship between exercise during pregnancy and preterm birth, including 41 studies (20 randomised controlled trials, and 21 cohort studies). The authors found no studies reporting an association between exercise during pregnancy and a higher risk of preterm birth. In fact they concluded that active pregnant women compared with inactive pregnant women had a reduction of 10-14% in the risk of preterm birth, supporting the recommendations for pregnant women to be active most of the days or every day (Aune D, Schlesinger S, Henriksen T, Saugstad OD, & Tonstad S, 2017).

Only one systematic review and meta-analysis of randomised controlled trials assessing exercise during pregnancy and the risk of preterm birth with overweight and obese pregnant women was found. The review involved 1,502 overweight or obese pregnant women included in nine randomised controlled trials were studied. Interventions involved at least three aerobic exercise sessions per week, lasting 30 to 60 minutes. All participants were randomised in early pregnancy to the intervention or control group. Participants who participated in the study groups showed a lower percentage of preterm birth (deliver earlier than 37 weeks of gestation) in contrast to participants in the control groups (RR 0.62; 95% CI 0.41-0.95). The authors concluded that overweight and obese pregnant women should be advice to participate in aerobic activities at least three times per week to reduce the risk of preterm birth (Magro-Malosso ER, Saccone G, Di Mascio D, Di Tommaso M, & Berghella V, 2017).

1.3.5. Barriers to exercise in obese pregnant women.

Excess weight itself implies a harder cardiorespiratory effort during exercise for obese pregnant women. The typical symptoms and physiological changes that occur during pregnancy, such as tiredness, breathlessness, increased joint laxity, and changes in posture and balance, because of the modification of the centre of gravity, make it more difficult for pregnant women to be physically active. Besides, concerns about the potential harm to the baby due to exercise is another reason that discourages pregnant women from exercising (Seneviratne SN et al., 2014; Sui Z & Dodd JM, 2013).

There are also external barriers which prevent pregnant women from being more active. Lack of suitable facilities to exercise, or the unaffordable prices of gym/leisure centre memberships, also lack in time, over protection from the family members, and even self-image might be a huge barrier to morbidly obese pregnant women as they do not like to show themselves in public (Seneviratne SN et al., 2014).

Although obese pregnant women are mostly aware of the benefits of physical activity for their pregnancy, i.e. they know that this might help labour, weight management, and physical and mental health, there is a lack of knowledge on the potential benefits of being active for the baby (Denison FC et al., 2015; Weir Z et al., 2010). Women also stated that they are not sure of what to do, or what to avoid to be more active (Denison FC et al., 2015). Obese pregnant women seemed to be aware of the adverse effects of obesity on maternal health outcomes; nonetheless, the barriers to be active still appear to be greater than the motivations (Sui Z & Dodd JM, 2013).

Also, obese pregnant women have declared that the advice received from healthcare providers on the benefits of exercising during gestation was inadequate and limited on safety matters, as well as proper ways to exercise (Denison FC et al., 2015). The accent on the information received was more on diet rather than on physical activity, inconsistent or even contradictory advice, or not receiving advice on physical activity at all. Some reported they were even advised to be careful and restrict exercise during pregnancy. In general, obese pregnant women perceive that healthcare providers' knowledge about physical activity during pregnancy is inappropriate and limited (Denison FC et al., 2015; Seneviratne SN et al., 2014; Sui Z & Dodd JM, 2013; Weir Z et al., 2010). Besides, it has been described that health care providers have usually not a formal instruction to prescribe physical activity to pregnant women (Ehrsam R et al., 2009). Not much is known about the effects of physical activity in pregnancy among morbidly obese pregnancies, however no harmful effect has been described. And, to the best of our knowledge, only a few studies have addressed these quality aspects related to exercising during pregnancy for morbidly obese pregnant women. All in all, it seems likely that more studies, better information, motivation, guidance, and support to engage in physical activity should be addressed into maternity care (Seneviratne SN et al., 2014), mostly for obese and morbidly obese pregnant women.

Morbidly obese pregnant women perceive that the exercise programs are not practical, or are unrealistic for their condition, suggesting that exercise strategies would be more beneficial and helpful if they were individually designed, and developed specifically tailoring very obese pregnant women (Denison FC et al., 2015).

Given the caveats of the studies that have been conducted to date, and the barriers that may prevent morbidly obese pregnant women from participating in interventions that increase physical activity, it was hypothesised that an alternative strategy may be a realistic option. The proposal was to move the focus away from increasing physical activity (which for reasons outlined has multifactorial challenges) to trying a different approach i.e. to reduce time spent sedentary.

1.4. Sedentary behaviour

1.4.1. Definition of Sedentary behaviour

Sedentary behaviour is defined as waking activities expending 1.5 METs or less, while reclining, lying or sitting (Tremblay MS et al., 2017). However sedentary behaviour cannot be confounded with physical inactivity, which should be understood as doing less physical activity than the recommended (BHF National Centre, 2012; Clark BK et al., 2009). There are different markers of sedentary behaviour, including television viewing and total sitting time (Atkin AJ et al., 2012). Too much time sedentary is associated with many adverse health effects including type 2 diabetes, obesity and premature mortality, even for active subjects (BHF National Centre, 2012; Katzmarzyk PT, Church T, Craig CL, & Bouchard C, 2009; Martin A et al., 2015; Rezende LFMd, Lopes MR, Rey-López JP, Matsudo VKR, & Luiz OdC, 2014; Rezende LFMd et al., 2016).

1.4.2. Methods to assess sedentary behaviour

To study sedentary behaviour, the use of high-quality assessment methods is really important, particularly if the aim is to identify causal associations on health effects, but also to describe the prevalence and patterns of sedentary behaviour in different populations over time (Atkin AJ et al., 2012).

According to The Sedentary Behaviour and Obesity Expert Working Group: Review of the Current Scientific Evidence, there are two main classifications of assessment methods for sedentary behaviour, usually the same used to assess energy expenditure. Objective devices such as accelerometers, pedometers and others, can calculate the time spent in sedentary behaviour, whilst non-objective methods, such as self-reported questionnaires, and activity diaries, can estimate sedentary behaviour (The Sedentary Behaviour and Obesity Expert Working Group et al., 2010).

1.4.3. Prevalence of sedentary behaviour

Nowadays, in developing and non-developing countries, it is common to find high levels of sedentary behaviour (Clark B & Sugiyama T, 2015). In the USA in a study aiming to describe the amount of time spent in sedentary behaviour between 2003 and 2004, the authors included 6,329 subjects of six or more years old. Sedentary behaviour was objectively assessed using the Actigraph accelerometer (model 7164, Actigraph LLC Fort Walton Beach, Florida), and the findings showed that children and adults spent approximately 54.9% (7.7 hours per day) of their waking time sedentary, which increased significantly as ageing advanced (Matthews CE et al., 2008). One study using the IPAQ assessed time sitting among adults between 18 and 65 years old of 20 countries worldwide. The authors observed that on average participants spent five to six hours per day sitting. The lesser median of sitting time was reported in Portugal, Brazil and Colombia, in contrast to Saudi Arabia, and Japan, which populations spent the highest sitting time levels (Bauman A et al., 2011). In other study, researchers found that 41.5% of the studied subjects spent at least four hours per day sitting, more specifically, in Africa people were less sedentary, as 37.8% of the people spent four or more hours per day sitting, compared with the Americans (55.2%), and 64.1% of the Europeans. Researchers did not find significant differences between genders, but observed that the proportion of subjects aged 60 or more years old spending four hours sitting per day was significantly greater (Hallal PC et al., 2012).

Yet in 2000 it was suggested that sedentary behaviour itself should be studied and addressed as an issue for public health action, independent of physical activity behaviour (Owen N, Leslie E, Salmon J, & Fotheringham M J, 2000). Sedentary behaviour has been reported as a potentially key risk factor for chronic disease in 2009 (Owen N, Bauman A, & Brown W, 2009). Consequently, as sedentary behaviour was not yet considered as an important risk factor for health, decades ago everywhere, long-term data is lacking. Another reason why sedentary behaviour was not assessed was that specific methods were not available, making it difficult to study trends (Bauman A et al., 2011; Bennie JA et al., 2013).

Nowadays sufficient data is available on the prevalence of sedentary behaviour, allowing researchers to study trends. Most trends show that sedentary behaviour has been increasing around the world in the last decades (Brownson RC, Boehmer TK, & Luke DA, 2005; Medina C, Tolentino-Mayo L, Lopez-Ridaura R, & Barquera S, 2017; Ng SW & Popkin BM, 2012). However some contradictory data has been published in

2015, regarding sedentary behaviour trends among European countries, suggesting that sitting time may not be increasing in the European region. The study assessed sedentary behaviour using the Eurobarometer surveys (European Commission, 2014), at three time points (2002, 2005, and 2013) over the past 15 years across 27 countries. The authors explained that an increase in sedentary behaviour was observed in the proportion of people who sit for more than seven and a half hours per day, but for low sitting time (0-4.5 hours per day), or middle (4-7.5 hours per day), no significant changes were observed. Additionally, the authors acknowledged that sedentary behaviour was assessed using a self-reported questionnaire, the IPAQ, which might underestimate time sitting. Besides the question used for the sitting time in 2002 and 2005 used an open ended scale, which changed to a categorical scale in 2013. That also might have influenced the answers. The authors concluded that due to the increased attention by the media on sedentary behaviour, people might be aware of the health risks associated to sedentary behaviour, making them to change their behaviour to be healthier by sitting less, or on the contrary, underreporting the real time they spent sedentary (Milton K, Gale J, Stamatakis E, & Bauman A, 2015).

Even though it is known that there are many different types of sedentary behaviour, television viewing is by far the most prevalent, in terms of what people spend more time in sedentary behaviour (Grøntved A & Hu FB, 2011; The Sedentary Behaviour and Obesity Expert Working Group et al., 2010), nevertheless in a study assessing 2,046 subjects (1,300 women and 746 men) the authors observed that television viewing is a good indicator of sedentary behaviour for women, but not necessarily among men, who spent significantly more time than women in other sedentary behaviour different than television viewing (Sugiyama T, Healy GN, Dunstan DW, Salmon J, & Owen N, 2008).

When looking at women's behaviour, there are some inconsistencies in the literature. In a systematic review, the authors concluded that apart from time spent playing video games, where men spend significantly more time than women, gender apparently does not influence sedentary behaviour (Rhodes RE, Mark RS, & Temmel CP, 2012). In one study the authors found that women were more sedentary than men until reaching 60 years old, when men became more sedentary. Between 70 and 85 years of age, men spent 9.5 and women 9.1 hours per day in sedentary behaviour (Matthews CE et al., 2008).

1.4.4. Consequences of sedentary behaviour for health

1.4.4.1. Type 2 Diabetes Mellitus

Several systematic reviews and meta-analysis have reported a strong association between sedentary behaviour and type 2 Diabetes Mellitus, independent of physical activity habits. A meta-analysis developed in 2012, including ten studies confirmed that strong association, observing an increase of 112% on the relative risk of diabetes, when compared the lowest and the greatest sedentary time (Wilmot EG et al., 2012). In other publication which focused on systematic reviews and meta-analysis on the effects of sedentary behaviour on health outcomes (Rezende LFMd et al., 2014), on five systematic reviews the authors found a significantly positive association between type 2 diabetes mellitus and sedentary behaviour in adults, regardless of physical activity levels (Grøntved A & Hu FB, 2011; Proper KI, Singh AS, van Mechelen W, & Chinapaw MJM, 2011; Thorp AA, Owen N, Neuhaus M, & Dunstan

DW, 2011; van Uffelen JGZ et al., 2010; Wilmot EG et al., 2012). Using watching television as sedentary behaviour, a meta-analysis showed that the risk of type 2 diabetes was 20% increased among those watching television for more than two hours per day, including data from four studies (Grøntved A & Hu FB, 2011).

Grøntved and Hu, in 2011 carried out a meta-analysis showing that for every two hours per day of television viewing the absolute risk difference of type 2 diabetes in the USA, was 176 cases per every hundred thousand subjects per year. Moderate heterogeneity was observed between studies (I^2=50.4%; p=0.11) (Grøntved A & Hu FB, 2011).

In another study, the authors aimed to examine the association between fasting and two hours post-challenge plasma glucose levels, during an oral glucose tolerance test, and television viewing, assessed using a self-reported questionnaire, among adults without diabetes. Including 8,357 subjects, a significant positive association of television viewing and two hours post challenge plasma glucose levels among women was observed, but there was no association with fasting plasma glucose. Among men no association was observed between television viewing and glycaemic measures. The authors concluded that reducing sedentary behaviour is a key factory to prevent type 2 diabetes, mostly in women (Dunstan DW et al., 2007).

1.4.4.2. Risk of cardiovascular disease

In an overview of systematic reviews, published in 2014, no agreement was found on the effect of sedentary behaviour on cardiovascular disease, based on four systematic reviews (Rezende LFMd et al., 2014). Two meta-analyses reported a positive and significant association between greater sedentary behaviour and the risk of cardiovascular disease, with an increased risk of cardiovascular disease of 147%, based on three prospective studies (Wilmot EG et al., 2012). On the other meta-analysis the authors included four studies looking at the association between sedentary time and the risk of cardiovascular disease, finding a relative risk of 1.15 for cardiovascular disease. A linear increase in dose-response for the risk for cardiovascular disease was found with the number of hours per day of television watching (Grøntved A & Hu FB, 2011).

In a study carried out in Australia, looking at the associations between time spent sedentary and waist circumference, triglycerides, HDL cholesterol, resting blood pressure, fasting plasma glucose, and a clustered metabolic risk score (a score usually calculated by three or more of the following risk factors: adiposity, hypertension, hyperglycaemia, low level of HDL-cholesterol and high triglycerides) (Machado-Rodrigues AM et al., 2014). One hundred sixty-nine adults without known diabetes took part. Sedentary behaviour was objectively assessed using an accelerometer. Researchers found that sedentary time was significantly linked with clustered metabolic risk and waist circumference, independent of time spent in moderate to vigorous activities (Healy GN, Wijndaele K, et al., 2008).

1.4.4.3. Obesity

In a study conducted in Ireland assessing 396 subjects, the authors aimed to investigate associations between inflammatory status, usually used as a marker of obesity, and objectively measured physical activity. More specifically researchers were interested in studying the effect of substituting daily sedentary behaviour with light activity or moderate to vigorous physical activity. A better inflammatory profile (defined as higher adiponectin and lower complement component C3, leptin, interleukin 6 and white blood cell concentrations) was associated with 30 minutes of replacing sedentary time with moderate to vigorous physical activity, but no significant effects were observed by changing sedentary time with light activity. Additionally the highest sedentary time was observed among obese participants (Phillips CM et al., 2017). Additionally, other researchers also studied the link between sedentary behaviour and inflammatory indicators, which in a low but chronic level are a characteristic of obesity. A positive association between time spent sedentary and some inflammatory factors was observed, including higher concentrations of CRP, Interleukin 6, leptin, and complement component 3 which plays an essential role in the immune response (Hertle E, van Greevenbroek MM, & Stehouwer CD, 2012).

In a large study carried out in Finland, including 1,993 young adults (1,084 women and 909 men), researchers looked at the association between sedentary behaviour and obesity, observing a significant direct association between total sedentary time and BMI, and with waist circumference. They also found a significant direct association between waist circumference and BMI with total sedentary time, television watching, and screen time (television viewing and computer hours) ($p<0.05$). In addition, among women a significant direct association between waist circumference and BMI with computer time and listening to music was observed. A self-administered questionnaire was employed to assess sedentary behaviour (Heinonen I et al., 2013).

In an overview of systematic reviews (Rezende LFMd et al., 2014), three systematic reviews studied the association of sedentary behaviour with risk of obesity, adiposity, and weight, among adults, concluding that the evidence is insufficient to confirm any association. One systematic review reported that self-reported sedentary behaviour is consistently associated with weight gain along the lifespan, but no clear association was observed for weight gain during adulthood, and only one of three studies using objective methods to assess sedentary behaviour showed an association with obesity markers (Thorp AA et al., 2011). For the association of sedentary behaviour and body weight, a similar conclusion was reached by other systematic review, stating limited evidence, mostly based on inconsistencies between the findings, to support that association (Proper KI et al., 2011). In the last systematic review included in the overview, where the authors studied the relationship between occupational sitting time and health risks, they also found limited evidence to proof it, due to the heterogeneity between study designs which made it difficult to reach a conclusion (van Uffelen JGZ et al., 2010).

1.4.4.4. All-cause mortality

Several publications have reported associations between sedentary behaviour and all-cause mortality. In one meta-analysis including three papers and involving 26,509 subjects, the authors reported that per every two hours of television viewing per day the absolute risk difference for all cause-mortality per year was estimated in 104 deaths per 100,000 subjects (Grøntved A & Hu FB, 2011). In another meta-analysis, studying all cause-mortality induced by daily sitting time, including six studies with 595,086 participants, authors reported that 5.9% of all-cause mortality was attributable to total daily sitting time, after taking physical activity into account (Chau JY et al., 2013).

Similarly, in a large study analysing data from 54 countries, the authors reported that around 433,000 deaths per year were attributable to sitting time, equivalent to

3.8% of all cause-mortality. They also reported that Europe was the second region with the highest rate of all-cause mortality due to sitting time, after the Western Pacific Region, highlighting that life expectancy in those countries would improve by 0.20 years if sitting time would be eradicated (Rezende LFMd et al., 2016).

In one large prospective study carried out in the USA studying 240,819 adults, after adjusting for moderate to vigorous physical activity, and other potential risk factors, researchers observed a positive association between prolonged time of television viewing and total sitting time, with all-cause mortality, even among active subjects (more than seven hours of high levels of moderate to vigorous physical activity per week). Television watching of seven hours or more per day was associated with 50% higher risk of all-cause mortality. When compared by categories of television viewing, those reporting viewing seven or more hours of television had 60% higher risk of all-cause mortality than those who reported viewing less than one hour daily (Matthews CE et al., 2012).

1.4.4.5. Depression

One systematic review showed a positive association between time spent watching television and depressive symptoms in all the four studies included in the systematic review assessing television viewing. No association was observed between time of computer use and depression, in any of the three included studies (Rhodes RE et al., 2012).

In another study, the authors assessed sedentary behaviour using a sedentary index which considered time using a computer or spent watching television, in hours per week. Studying 7,991 participants, a direct dose-response association between the incidence of mental disorders and sedentary behaviour was found (p=0.04). Besides, it was observed that the risk of developing a mental disorder was 31% higher among those who reported to spend more than 42 hours per week in sedentary behaviour, compared with the subjects who reported spending less than 10.5 hours per week sedentary (OR 1.31; 95% CI 1.01-1.68). Specifically on the incidence of depression, no significant associations was found with sedentary behaviour (OR for the highest level of the sedentary index =1.35; 95% CI 0.94-1.94; p for trend=0.27) (Sanchez-Villegas A et al., 2008).

1.4.5. Physiology of sedentary behaviour

It is interesting, in order to explain sedentary behaviour physiology, that a link has been found between aging and sedentary behaviour, as it seems that aging intensifies the increase of time sedentary along lifetime, as well as the decrease of cardiovascular, muscular, and cardiorespiratory function (Hamilton MT, Hamilton DG, & Zderic TW, 2007; Thyfault JP, Du M, Kraus WE, Levine JA, & Booth FW, 2015).

It has also been suggested that continuing sedentary behaviour might strengthen the decline of maximal aerobic capacity and muscle strength, but the explanation of mechanisms behind is lacking (Thyfault JP et al., 2015). Even when some authors have mentioned that cognitive function might be affected by sedentary behaviour, not direct association was observed with sedentary behaviour (Thyfault JP et al., 2015), but with inactive subjects, or on the contrary with aerobic exercise (Voss MW, Nagamatsu LS, Liu-Ambrose T, & Kramer AF, 2011).

An association between inactivity and lipoprotein lipase control has been identified which seems to help to initiate the adverse effects of sedentary behaviour in health.

Lipoprotein lipase is an enzyme involved in the uptake of free fatty acids and triglycerides into HDL cholesterol, and skeletal muscle development (Bey L & Hamilton MT, 2003; Thorp AA et al., 2011; Wilmot EG et al., 2012). Studies with rats have found that immobility stimulates the suppression of lipoprotein lipase activity in legs skeletal muscles involved in posture maintenance, lowering the levels of HDL cholesterol in plasma, and increasing the cardiovascular risk. Importantly, it was observed that lipoprotein lipase activity did not increase in the same posture muscles after intense physical activity (Hamilton MT et al., 2007; Hamilton MT et al., 2008), similarly when the rats took part in light activities such as walking or standing the suppression of lipoprotein lipase activity was no longer observed (Bey L & Hamilton MT, 2003; Thorp AA et al., 2011).

Sedentary behaviour has been reported to deactivate glucose transporters type 4 (GLUT-4) translocation of to the muscle cell surface, reducing glucose uptake secondary to the muscle inactivity (Leitzmann MF, Jochem C, & Schmid D, 2017; Thorp AA et al., 2011).

Varied biochemical adverse effects of sedentary behaviour, such as Inflammation, endothelial dysfunction, and excess free radicals can be generated by high levels of free fatty acids, triglycerides, and glucose in the circulation. Further on, if those levels are maintained for long periods, the risks can drive to the development of cardiovascular risk factors and coronary heart disease (O'Keefe JH & Bell DS, 2007; Thorp AA et al., 2011). Those effects may also be involved with the development of deep venous thrombosis which has been related with sitting for long periods, and is a dangerous condition for health, defined as the appearance of blood clots, usually in deep leg veins (Bey L & Hamilton MT, 2003).

Some publications have mentioned the physiology of sedentary behaviour however, after reading, it seems as if they refer more to the inactivity physiology rather than sedentary behaviour physiology, although it is explained that sedentary behaviour is different from lack of exercise. The authors are aware that it is important to learn which physiological effects are associated with inactivity and which are associated with sedentarism, to differentiate them. All in all, more studies are needed (Hamilton MT et al., 2008).

1.4.6. Sedentary behaviour and pregnancy

In pregnant women, the prevalence of sedentary behaviour seems to be similar or even greater. In a study with pregnant women assessing sedentary behaviour objectively, the authors observed that at week 35 of gestation, active pregnant women (n=13) spent 70% of their time awake in sedentary behaviour, meanwhile inactive pregnant women (n=33) spent 80% of their time awake sedentary (p=0.005) (Di Fabio DR, Blomme CK, Smith KM, Welk GJ, & Campbell CG, 2015). At the time of starting the work in this thesis there was little literature on time in sedentary behaviour during pregnancy and the potential associations with adverse pregnancy outcomes. A handful of studies had identified that increased time spent sedentary was associated with factors such as higher maternal levels of LDL cholesterol (Loprinzi PD, Fitzgerald EM, Woekel E, & Cardinal BJ, 2013), and CRP (Hawkins M, Pekow P, & Chasan-Taber L, 2014; Loprinzi PD et al., 2013), as well as a higher risk of developing preeclampsia (Spracklen CN et al., 2016), and GDM (Anjana RM et al., 2016; Leng J et al., 2016). And for the babies larger new born abdominal circumference (Hayes L, Bell R, Robson S, & Poston L, 2014), and higher risk of macrosomia (birthweight>4000g) (Reid EW, McNeill JA, Alderdice FA, Tully MA, &

Holmes VA, 2014). However there are inconsistencies in the literature, and, little is known about sedentary behaviour in morbidly obese pregnant women.

1.4.7. Interruptions to sedentary time

In the last years, researchers have set the attention not only on sedentary time, but also on the interruptions to sedentary time. Interruptions to sedentary time are a different measure distinct than the total time spent in sedentary activities, which might involve activities of light intensity such as a step, or walking or even standing from a sitting position. It has been suggested that interruptions to sedentary time are beneficially associated with reduced metabolic risks and improved body composition, independent of the total sedentary time. In a cross-sectional study including 168 participants, researchers studied the association between interruptions to sedentary time (if accelerometer counts rose up to or above 100 counts per minute), which on average lasted less than five minutes, and metabolic biomarkers outcomes, finding a significant inverse association between the total number of breaks to sedentary time, and lower waist circumference, BMI, two hours plasma glucose, and triglycerides (Hamilton MT et al., 2008; Healy GN, Dunstan DW, et al., 2008; Mottola MF, 2016; Swartz AM, Squires L, & Strath SJ, 2011).

In a review published in 2015, including 17 prospective experimental studies looking at the effect of breaking up prolonged sitting time, Benatti & Ried-Larsen (2015) observed that based on the literature there is sufficient evidence of the beneficial effect of interrupting prolonged time sitting on health, particularly on metabolic results. But to prevent successfully the adverse consequences of prolonged sitting, the intensity, frequency and type of activity performed during the interruptions may vary depending on targeted population, therefore interventions have to be designed accordingly (Benatti FB & Ried-Larsen M, 2015).

In another small study conducted with 20 adults, the authors studied the participants for two hours testing four different options. The first included just 30 minutes sitting, second consisted of 29 minutes sitting plus one minute walking interruption in the middle, the third consisted of 28 minutes sitting and a two minute walk interruption in the middle, and the last consisted of 25 minutes sitting with a five minute walk interruption in the middle. The energy expenditure of the participants was assessed by indirect calorimetry, to compare the options against the first one, which was sitting for 30 minutes without interruption, observing an increase in the energy expenditure of 7.3% when interrupted for one minute walk, 17% increase when interrupted for two minute walk, and 37% increase when the interruption lasted for five minute walk. The authors suggested that the difference in energy expenditure might be huge if those interruptions would be multiplied for every hour during the day, reducing the risk of obesity, and risks linked to weight control management (Swartz AM et al., 2011).

Another study aimed to examine and compare the effect of sitting without breaks and sitting with active breaks, on glucose and insulin levels. Nineteen overweight/obese adults were randomly assigned to take part in the trial, based on three different treatments, one based on sitting with no interruption, one with sitting breaks of two minutes long based on light physical activity, every 20 minutes, and one with sitting interrupted with two minute breaks of moderate intensity physical activity every 20 minutes. Subjects were provided with a standardised test drink after the initial two hour period of uninterrupted sitting. Both treatments with interruptions showed significantly lower glucose levels and significantly reduced insulin levels, compared with the uninterrupted sitting treatment. Though the authors concluded that breaking up sitting time with short periods of light or moderate-intensity physical activity might decrease postprandial glucose and insulin levels among overweight or obese adults (Dunstan DW et al., 2012). Similarly, in another study, researchers examined the effect of interrupting prolonged sitting time on cardiometabolic markers, with light intensity walking or standing. Plasma glucose, blood pressure were measured every hour, and triglycerides, total cholesterol and HDL cholesterol were assessed at baseline and five hours later, to ten non-obese participants. Three trials were conducted, one with no breaks during an hour, one hour sitting with breaks of two minutes standing every 20 minutes, and one hour sitting with breaks of two minutes light walking every 20 minutes. Subjects were provided with two standardised drinks during the experiment, after consumption and for the next five hours, blood samples were collected every hour to assess the effect of the different interventions and hourly. Also blood pressure was read every hour. The trial with the two minute light walking break presented a significantly lower glucose area under the curve, compared to the other two trials, and no difference was observed between sitting for an hour, and interrupting with two minutes standing every 20 minutes. No differences were observed between the three trials on blood pressure, or lipid markers. These results suggest that interruptions to long time spent sitting with light physical activity, but not standing, potentially improve postprandial responses (Bailey DP & Locke CD, 2015).

Finally a pilot study reported the effects of breaking up prolonged sitting by brief bouts of light-intensity walking, on self-reported fatigue, cognition, neuroendocrine biomarkers and cardiometabolic risk markers in overweight/obese adults. The 19 overweight/obese subjects who took part in the trial were asked to participate in an active treatment based on short breaks to sitting time, of light walking activity, and a sedentary treatment with no breaks to sitting time. Reported fatigue levels were lesser for the active treatment, compared with the sedentary treatment, at four hours and seven hours, meanwhile heart rate was increased during the active treatment, compared with the sedentary treatment, after four and seven hours, which suggests that active breaks to long bouts of sedentary or sitting time might help to reduce fatigue perception, however further research is required to identify other factors involved, mostly related to the occupational environment (Wennberg P et al., 2016).

1.4.7.1. Interruptions to sedentary time during pregnancy

At the time of writing this thesis only one study was found reporting interruptions to sedentary time in pregnancy. The study assessed the transitions between sitting to standing, using an objective device that evaluates postural allocation, and found no differences in sit/lie and upright time between week 18 and 35 weeks of gestation. However, the number of transitions between sedentary (sit/lie) to upright per day and the number of sit/lie bouts increased significantly from week 18 to week 35 of gestation whilst the length of sit/lie bouts in minutes per day significantly decreased across gestation (Di Fabio DR et al., 2015). It is dificult to try to explain these results; all in all, from week 18 to week 35 of gestation women interrupted their time sedentary more times, meaning that time sedentary was divided into more but shorter periods. This should be less risky, because the adverse effects of sedentary behaviour in general, are associated with long periods of sedentary activity.

1.4.8. Interventions to reduce sedentary behaviour

A group of experts in sedentary behaviour, all academics from the USA met to carry out a workshop called "*Sedentary Behavior: Identifying Research Priorities*", to discuss regarding interventions to reduce sedentary behaviour (Manini TM et al., 2015). To report what was discussed and presented in the workshops, they published the paper that is explored as follows. Based on the data it was suggested that to design interventions with the aim of reducing sedentary behaviour, it is essential to agree in one definition for sedentary behaviour, as interventions should be obviously influenced by definition. Besides, it was recommended to assess the feasibility, effectiveness and acceptability of the strategies to reduce sedentary behaviour, before implementing anything, considering the features of the population involved (e.g., age, health status, occupation), as strategies might have different effects and consequences with different kind of participants. Additionally it was ratified that based on the data, randomised controlled trials are the best, and the recommended method to address interventions aiming to reduce sedentary behaviour, whilst technology, such as phone apps specially designed to promote the decrease of time sedentary have been suggested as potentially effective and a helpful option (King AC et al., 2013) to have in mind based on the evidence (Manini TM et al., 2015).

In a systematic review and meta-analysis (Martin A et al., 2015) exploring interventions with the potential to reduce sedentary behaviour, 51 randomised controlled trials were included, of these 34 showed that among study groups sedentary time decreased in 22 minutes per day compared to control groups (n=5,868; 95% CI−35.81—8.88; p=0.001; I^2=71%). Whilst 20 studies including interventions aiming to modify lifestyle, decreased sedentary behaviour in 24.18

minutes per day (n=3,881; 95% CI −40.66- −7.70; p=0.004; I^2=75%). Two studies involving interventions focusing exclusively on sedentary behaviour, managed to reduce sedentary behaviour in 41.76 minutes per day (n=62; 95% CI−78.92-−4.60; p=0.003; I^2=65%). No reduction in sedentary behaviour was observed among interventions using physical activity, or a combination of physical activity and sedentary behaviour (Martin A et al., 2015).

In a study carried out in Ireland, the authors aimed to study the effect of replacing sedentary behaviour with light or moderate to vigorous physical activity, on the levels of inflammatory markers in adults. They involved 396 participants, and assessed activity behaviour using the GENEActiv accelerometer, finding favourable outcomes, as replacing sedentary activities with moderate to vigorous physical activities changed beneficially the inflammatory profile. No significant differences were observed when replaced sedentary for light activities (Phillips CM et al., 2017).

It has been largely explained that too much time in sedentary behaviour might be detrimental for health (Dunstan DW et al., 2007; Healy GN et al., 2007; Healy GN, Wijndaele K, et al., 2008; Rezende LFMd et al., 2014; Rezende LFMd et al., 2016). It has also been explained that more time spent in light-intensity physical activity might be beneficial for health (Barakat R et al., 2016; Hamilton MT et al., 2008; Healy GN, Wijndaele K, et al., 2008; Mottola MF, 2013). And that there is an inverse, and strong relationship between light-intensity physical activity and sedentary behaviour. All together suggests that by promoting to increase the time people spend in light-intensity physical activity the time spent in sedentary activities might be reduced, which offers a feasible approach to minimise the adverse consequences of too much time sedentary (Hamilton MT et al., 2008).

1.4.9. Summary

Overall the evidence supports that obesity is associated with negative effects for pregnancy, for mothers and offspring. Different studies using physical activity interventions have tried to help pregnant women and obese pregnant women to reduce those risks associated with obesity. Prolonged time in sedentary behaviour is also associated with adverse effects for health, and so might have similar negative effects in pregnancy as well. However there are few studies regarding sedentary behaviour during pregnancy, and it is not known how pregnant women behave in relation to sedentary activities during pregnancy. The focus of this thesis therefore is to investigate sedentary behaviour during pregnancy and to explore whether interventions focusing on decreasing time spent sedentary are a suitable approach for obese pregnant women.

1.5. Hypothesis

An active sitting exercise intervention for obese pregnant women will decrease time spent sedentary and increase energy expenditure.

1.6. Aim and Objectives

1.6.1. Aim

The overarching aim of this thesis is to explore sedentary behaviour among obese pregnant women and to propose an intervention to reduce the time obese pregnant women spend sedentary, through an active sitting exercise intervention.

1.6.2. Objectives

- To conduct a systematic review of the literature to determine:
  a) the proportion of time spent in sedentary behaviour among pregnant women.
  b) the association of sedentary behaviour with pregnancy outcomes in mothers and offspring.
- To estimate total energy expenditure, and energy expended in sedentary activities in morbidly obese and lean pregnant women using non-objective and objective data collected from women participating in a cohort study.
- To assess the feasibility of an active sitting exercise intervention for morbidly obese pregnant women, designed using a patient involvement in research method.

Chapter II. Sedentary behaviour during pregnancy: A systematic review

Chapter II. Sedentary behaviour during pregnancy: A systematic review

2.1. Introduction

Sedentary behaviour is thought to be a key risk factor for health, because several studies have shown that spending excessive time sedentary is associated with health problems, such as obesity, type 2 diabetes, and premature mortality, even among individuals who meet recommended targets for physical activity behaviour (BHF National Centre, 2012; Katzmarzyk PT et al., 2009; Martin A et al., 2015; Rezende LFMd et al., 2014; Rezende LFMd et al., 2016). All activities performed in a reclining, sitting or lying position, which expend very low energy, usually between 1 and 1.5 METs, apart from sleeping, are considered as sedentary behaviour (Tremblay MS et al., 2017).

In view of these studies showing the adverse consequences of spending too much time sedentary for health in the general population, we hypothesised that sedentary behaviour during pregnancy might also have adverse health consequences for mothers and offspring. In this chapter a systematic review was conducted in order to identify the prevalence of sedentary behaviour in pregnancy, and to determine whether there were any associations between sedentary behaviour and pregnancy outcomes for mothers and offspring.

The aim of this systematic review was:

a) To determine the time spent in sedentary behaviours and the prevalence of sedentary behaviour among pregnant women, and

b) whether sedentary behaviour are associated with pregnancy outcomes for mothers and offspring.

2.2. Systematic review until October 2015

The review was registered on Prospero – registration number CRD42015023611.

The systematic review was accepted and published in the International Journal of Behavioural Nutrition and Physical Activity. Fazzi C, Saunders DH, Linton K, Norman JE, Reynolds RM. Sedentary behaviours during pregnancy: a systematic review. Int J Behav Nutr Phys Act. 2017 Mar 16;14 (1):32. doi: 10.1186/s12966-017-0485-z.

Authors' contributions

Caterina Fazzi carried out the literature review, conducted all aspects of the review and wrote the manuscript.

Kathryn Linton carried out the literature review and approved the manuscript.

David Saunders supervised the conduct of the review and wrote the manuscript.

Jane Norman supervised the conduct of the review and approved the manuscript.

Rebecca Reynolds carried out the systematic review and wrote the manuscript.

The accepted version of the published manuscript is included as follows. The publication is attached as **Appendix 1**.

2.2.1. Manuscript

Abstract

Background: In the general population, at least 50% of time awake is spent in sedentary behaviours. Sedentary behaviours are activities that expend less energy than 1.5 metabolic equivalents, such as sitting. The amount of time spent in sedentary behaviours is a risk factor for diseases such as type 2 diabetes, cardiovascular disease, and death from all causes. Even individuals meeting physical activity guidelines are at a higher risk of premature death and adverse metabolic outcomes if they sit for extended intervals. The associations between sedentary behaviour with type 2 diabetes and with impaired glucose tolerance are stronger for women than for men. It is not known whether sedentary behaviour in pregnancy influences pregnancy outcomes, but if those negative outcomes observed in general adult population also occur in pregnancy, this could have implications for adverse outcomes for mothers and offspring.

We aimed to determine the proportion of time spent in sedentary behaviours among pregnant women, and the association of sedentary behaviour with pregnancy outcomes in mothers and offspring.

Methods: Two researchers independently performed the literature search using five different electronic bibliographic databases. Studies were included if sedentary behaviours were assessed during pregnancy. Two reviewers independently assessed the articles for quality and bias, and extracted the relevant information.

Results: We identified 26 studies meeting the inclusion criteria. Pregnant women spent more than 50% of their time in sedentary behaviours. Increased time in sedentary behaviour was significantly associated with higher levels of C Reactive Protein and LDL Cholesterol, and a larger newborn abdominal circumference. Sedentary behaviours were significantly higher among women who delivered macrosomic infants. Discrepancies were found in associations of sedentary behaviour with gestational weight gain, hypertensive disorders, and birth weight. No consistent associations were found between sedentary behaviour and other variables such as gestational diabetes. There was considerable variability in study design and methods of assessing sedentary behaviour.

Conclusions: Our review highlights the significant time spent in sedentary behaviour during pregnancy, and that sedentary behaviour may impact on pregnancy outcomes for both mother and child. The considerable heterogeneity in the literature suggests future studies should use robust methodology for quantifying sedentary behaviour.

Key words: Sedentary behaviours, sedentarism, pregnancy.

Background

Sedentary behaviours are activities that expend very low energy, close to the basal metabolic rate, without significantly increasing energy expenditure. This equates to activities such as sitting or lying, that utilise less than 1.5 metabolic equivalent units, or times the basal metabolic rate (1, 2). Sedentary behaviours are thus distinct from lack of physical activity, although the latter is sometimes mistakenly used as a marker of sedentary behaviour in the literature (3).

Epidemiological studies have shown that in the general adult population, around 55% to 60% of time awake is spent in sedentary behaviours (4, 5). In the UK, children, young people, adults and older adults, spend on average at least half of their waking hours being sedentary (6, 7). In pregnant women the situation appears to be similar or even worse (8-12), although the literature has not been systematically reviewed.

The quantity of time spent in sedentary behaviours is a key risk factor for diseases such as type 2 diabetes (13), cardiovascular disease (14), metabolic syndrome (15) and death from all causes (14, 16, 17). New evidence also suggests that sedentary behaviour has an adverse effect on mental wellbeing, including depression (3). Importantly some studies have exposed that even when individuals meet physical activity recommendations, they are still at a higher risk of premature death and adverse metabolic health if they sit for extended intervals (2, 18-20). Sedentary behaviours, mostly television watching, are also linked to high risk of obesity and type 2 diabetes in the general population, independent of physical activity levels (1, 20), and in some studies the associations between sedentary behaviours with type 2 diabetes and with impaired glucose tolerance were stronger for women than for men (18, 21, 22).

If the negative health outcomes associated with sedentary behaviour in the general population, also occur in pregnancy, this could have implications for development of cardiometabolic complications such as gestational weight gain, gestational diabetes mellitus and hypertension, as well as mental wellbeing. It is not known whether sedentary behaviour in pregnancy influences outcomes for the baby such as birthweight or gestation at delivery.

We aimed to carry out a systematic review of the literature investigating sedentary behaviours during pregnancy to determine:

a) the time spent in sedentary behaviours and the prevalence of sedentary behaviours among pregnant women, and
b) whether sedentary behaviours are associated with pregnancy outcomes in mothers and offspring.

Methods

Data sources and searches

The Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines were followed for the conduct (23), and the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines for the reporting of this systematic review (24). The systematic review was registered in PROSPERO with the number CRD42015023611.

Two researchers (CF, KL) independently performed the literature search using five different electronic bibliographic databases: MEDLINE, EMBASE, Web of Science, CINAHL and SPORTDiscus. The strategy (Figure 1) was developed using Boolean. In MEDLINE medical subject headings used were: pregnant women (used also for pregnant woman), pregnancy (used also for pregnancies and gestation), prenatal care and sedentary lifestyle (used also for sedentary lifestyles). In EMBASE, main terms used were: pregnant woman (used also for pregnant women), pregnancy (used also for child bearing, childbearing, gestation, gravidity, intrauterine pregnancy, labour presentation, pregnancy maintenance and pregnancy trimesters), prenatal care (used also for ante natal care, antenatal care and antenatal control), prenatal period (used also for antenatal period) and sedentary lifestyle (used also for sedentary life style). The following keywords were also used for plain text searching in all databases: pregnan*, gestation*, gravid*, antenatal, prenatal, sedentar*, sitting, television, screen-based, TV, watching and viewing. Recursive searching of reference lists of retrieved articles was performed to identify any additional studies.

Studies were included if the sample considered pregnant women over 16 years old, and if sedentary behaviours (specified as watching TV, sitting or lying, low energy expenditure activities, etc.) were assessed at any point during gestation. Only published studies were included. There were no exclusions related to study design, language, ethnicity, socioeconomic status, parity or physical condition.

Two reviewers (CF, KL) independently assessed articles for inclusion according to the inclusion/exclusion criteria. After screening the titles and abstracts, the reviewers selected potentially relevant studies. If it was not possible to determine relevance from titles and abstracts, full texts were retrieved. Any disagreements that could not be resolved by consensus were discussed with a third reviewer.

Two reviewers (CF, KL) independently extracted relevant information on study characteristics, methodology, and study results using a data extraction form in order to determine whether the study reported the time that pregnant women spent in sedentary behaviours, the prevalence of sedentarism among pregnant women, and whether the sedentary behaviours were linked to pregnancy outcomes.

For presentation in the tables reporting time and proportion of time in sedentary behaviours, we standardised the outcomes (converted to the same units) in order to make them comparable. Due to the heterogeneity of outcome data, a narrative synthesis was developed.

Quality and risks of bias were assessed using objective criteria relating to sample population and recruitment, reliability of instruments, use of validated outcome measures, follow-up, risk of bias and data analysis, using a quality assessment instrument that was modified from the Grading of Recommendations Assessment Development and Evaluation (GRADE) Guidelines used in assessment of clinical trials (25-28). A paper could attain a maximum score of 8, a score of 1-3 indicating poor quality, 4-6 intermediate, and 7-8 good quality.

Results

From 974 abstracts, 39 full text articles were assessed and 26 studies met the inclusion critera for the systematic review (Figure 1).

Characteristics of included studies

Characteristics of the 26 included studies are displayed in Table 1. Seventeen were cohort studies (8, 12, 29-43), seven were cross-sectional studies (9-11, 44-47), and two were randomised controlled trials (48, 49).

Most studies were carried out in the USA (n=11) and Europe (n=9), and the remaining were in China (n=2), Africa (n=1), Canada (n=1), Australia (n=1) and Singapore (n=1). One study included couples (for the purpose of this review we only considered data from the women, not the men) (33); two other studies included both pregnant and non-pregnant women (non-pregnant women were considered in this review when comparisons between the two groups were made) (33, 47). Three studies were conducted in Hispanic pregnant women (34, 40, 43), and one in Latina pregnant women (36). One study was conducted in nulliparous pregnant women, one in obese pregnant women (49), one in pregnant women with type 1 diabetes mellitus (41), and one in pregnant women with sedentary lifestyles (38). Thirteen studies utilised objective methods to assess sedentary behaviours (accelerometers, pedometers, combined heart rate and accelerometer device, and indirect calorimetry), and 13 studies employed non-objective measures including four administrating the Pregnancy Physical Activity Questionnaire (PPAQ), nine using another kind of survey or questionnaire (The Australian Women's Activity Survey, Modified version of the Kaiser Physical Activity Survey, Behavioral Risk Factor Surveillance System, modified version of the leisure time activity section of the Physical Activity Scale for the Elderly, and other type of non-objective appraisal methods) (Table 2). The PPAQ has been validated among pregnant women, similarly two of the administered surveys were also validated among pregnant women, meanwhile three studies used validated questionnaires, but not validated among pregnant women. Finally, four of the questionnaires were not validated.

Amount and proportion of time spent in sedentary behaviours (Table 3)

The amount of time spent in sedentary behaviours was estimated in eight studies using either objective (8-12, 30, 38, 44) or non-objective methods (35, 37, 42) (Table 3).

The time spent in sedentary behaviours during pregnancy assessed objectively, varied between 7.07 and 18.3 hours per day. Of these studies one declared that sleeping was included (9), two stated that sleep time was not considered (8, 11), and the rest did not declare anything regarding sleep (10, 12, 44). Meanwhile the study which assessed using a questionnaire found that women spent 2.4 hours per day watching television and the mean of total sitting time was 8.6 hours per day (42) (Table 3).

Among the five studies assessing the proportion of time spent in sedentary behaviours all used objective devices, finding that pregnant women spent more than 50% of their time (range 57.1% to 78%) in sedentary activities (8-12) (Table 3).

Definitions of sedentary behaviours

The definition of time spent in sedentary behaviours differed according to method of assessment. Studies that used accelerometers defined activities with less than 100 counts per minute as sedentary behaviours, while activities expending 1.5 metabolic equivalents or less was used for combined heart-rate and activity monitors. Meanwhile, non-objective methods focused mostly on television viewing and sitting time.

Prevalence of sedentarism among pregnant women (Table 4)

Five studies determined the prevalence of sedentarism among the pregnant population, all except one (30) used non-objective methods to assess activity behaviour, and all used their own cut-offs to classify women as sedentary. Two used the term "sedentary", defining this as <5000 daily steps (30) or considering women as 'sedentary' if they declared "watching television, or pursuing some other sedentary occupation" as the most appropriate description of their activities (35), respectively. One study focused on the second trimester of pregnancy and found that prevalence of sedentarism was 18% (30), the other study assessed women on the third trimester of pregnancy finding that 29% were sedentary (35). Three studies analysed the prevalence of sedentary women, however these three studies did not use the term 'sedentary', but used different activity categories defined variously by the authors as: "watching television (for a certain amount of time)", or being “mostly sitting”. One study found that 15.3% of the studied women watched television or videos for five or more hours per day (37), other study found that 34% viewed television two hours or more per day (29), and the last one found that 31.9% watched television more than 21 hours per week, i.e. about three hours per day (42). Additionally one of the studies found that 24% of women were “mostly sitting” during usual daily activities (37) (Table 4). Comparison of data was difficult due to different cut-offs to define sedentary behaviour and categorisation of sedentarism.

Change in sedentary behaviour during pregnancy

Among the included studies, five aimed to determine whether time spent in sedentary behaviours was stable or changed during gestation (8, 10-12, 37). Four of these studies examined minutes per day or percentage of day spent in sedentary activities based on objective measures (8, 10-12). Of these, only one found that the percentage of time awake spent in sedentary behaviours significantly increased between week 18 and 35 of gestation (8). Another study found that women spent a mean of 40 minutes (standard deviation ±75) less in “very light sitting activities” (activities that spend around 1.3 times the basal metabolic rate) in later gestation than in earlier gestation (38). The three studies which objectively assessed time or percentage of time of monitored time spent in sedentary behaviours, did not find significant differences in time spent in sedentary behaviours between trimesters of gestation (10-12). When focused on the number of sedentary pregnant women across gestation, more women were sedentary during the third trimester than during the second trimester (18%, n=155; 24.9%, n=215, respectively) (30). When the time spent between trimesters in TV watching and computer use was compared, no differences were found (37).

Five studies compared sedentary behaviours between pregnant and non-pregnant women (35, 38, 42, 43, 47). Four compared from before pregnancy to during pregnancy, and one compared pregnant women versus one year postpartum women (38). Three studies used non-objective methods (35, 42, 43), and two objective procedures (38, 47) to assess sedentary behaviours. All found that the time spent in sedentary activities is significantly greater among pregnant than non-pregnant women.

When the number of women that watched television for long periods was compared before and after pregnancy, one study observed that the number increased (42), and the other found no change (29).

Additional factors affecting sedentary lifestyles

Some studies considered additional factors which could influence the development of sedentary lifestyles. These factors included: smoking, meeting physical activity recommendations, parity, maternal age, and education level. Time spent in sedentary behaviours was significantly less among women who smoked cigarettes in the past five days, compared to those who did not (11). Time spent in sedentary behaviours at 35 weeks of gestation was significantly less among women meeting physical activity guidelines compared to women who did not (8). During pregnancy women expecting their first child decreased their sedentary time significantly more than non-pregnant women without children, as well as first time pregnant women also decreased their sedentary time significantly more than those expecting their second baby as pregnancy advanced (33). When the changes before and during gestation were compared, women aged 16–19 years, significantly decreased their sedentary activity compared to those aged 20–24 years. Women who had completed college, also significantly decreased their sedentary activity during pregnancy, compared with those with less than a high school education (43).

Interruptions during sedentary time

One study focused on the transitions between sit to stand, using an objective device that evaluates postural allocation (8). No differences were found in sit/lie and upright time between week 18 and 35 of gestation. However, the number of transitions between sedentary (sit/lie) to upright per day and the number of sit/lie bouts increased significantly from week 18 to week 35 of gestation, whilst the length of sit/lie bout in minutes per day significantly decreased across this gestation window.

Associations between sedentary behaviours and maternal and infant outcomes

Birth and gestation outcomes associated with sedentary behaviours were studied in 14 of the included studies (10, 12, 30-32, 34, 36, 39, 40, 44-47, 49). Of these, seven were focused on pregnancy outcomes including gestational weight gain (GWG) and maternal depression (12, 30, 34, 40, 44-46), five on metabolic outcomes (10, 36, 44, 47, 49), and five on infant outcomes (12, 31, 32, 39, 49).

Associations between sedentary behaviours and pregnancy outcomes (Table 5)

Three studies investigated whether there is an association between sedentary behaviours and gestational weight gain (12, 30, 40). One study found no association between percentage of time spent in sedentary behaviours with gestational weight gain at 15 weeks of gestation, between 15 and 32–35 weeks of gestation, or with gestational weight gain per week (12). Likewise, change in percentage of time in sedentary behaviours during 15 to 32–35 weeks of gestation was not associated with total gestational weight gain or with gestational weight gain per week. Another study also observed no significant associations between sedentary activity and inadequate or excessive gestational weight gain, at each stage of pregnancy (40). However, in another study the 'Active' group (named according to author´s categorisation) gained significantly lower maternal weight during the second and third trimesters than the 'sedentary' group (named according to author´s categorisation) (30).

Three studies explored the association between pregnancy sedentary behaviours and hypertensive disorders during gestation. Two studies found no association (34, 44), but one study found that women who had persistent sedentary work (and were not authorised to move from their work place during working hours), such as sewing operators, developed significantly more gestational hypertension than women in the control group, whose work was also mostly sedentary, but whom were allowed to move during working time, such as secretaries (46).

No association was found between pregnancy sedentary behaviours and depression (45).

Associations between sedentary behaviours and metabolic outcomes (Table 5)

The relationship between time spent in sedentary behaviours and fasting glucose levels was analysed in one study, finding a positive association (44). On the other hand, sedentary behaviours were not associated with altered insulin sensitivity (47), gestational diabetes mellitus (49), or abnormal glucose tolerance (36). Two studies found associations between sedentary behaviours and C-reactive protein (CRP) (10, 44). In one study sedentary time and proportion of wear time spent sedentary were positively associated with CRP among women in the second trimester, but this finding was no longer statistically significant in analyses adjusting for confounders (10). In the other study the positive association between sedentary behaviours and CRP levels remained after adjustment for confounders (44). A significantly positive association between time spent in sedentary behaviours and higher LDL cholesterol was found in one study, but no association was found with any other blood lipid marker (44).

Associations between sedentary behaviours and infant outcomes (Table 5)

Two studies found no association between birth weight and mother's sedentary behaviours during pregnancy (12, 32). One study found a significant association between lower birthweight with time spent in sedentary lifestyle in each trimester of gestation (31), whilst another found that women who delivered macrosomic infants (birthweight ≥4000g) spent significantly more time sedentary than women delivering offspring weighing less than 4000g (39). The one study exploring the correlation between the new born abdominal circumference (as an indicator for abdominal adiposity) with mothers' time spent sedentary found differing results according to gestation. At 16-18 weeks of gestation a significantly inverse association was found between infant abdominal circumference and time spent sedentary, however at 36 weeks of gestation, the relationship became significantly positive (49). No associations were found between sedentary behaviours and gestational length (12, 31), or risk of preterm delivery (31).

Quality assessment results

Both reviewers agreed that two (7.7%) of the studies were of good quality (48, 49), three (11.5%) were classified as of poor quality (37, 45, 46), and the rest 21 as intermediate (80.8%).

The two studies that were classified as good quality were randomised controlled trials.

Of those classified as poor quality the main reasons were small sample size (45, 46), use of a non-objective appraisal tool to classify women as sedentary (37, 45, 46) and lack of detail about the outcome measures (37, 46).

Discussion

Main findings

There is increasing interest in research in the general population about whether reducing time spent in sedentary behaviours has a beneficial effect on health (50, 51). Here we systematically reviewed the literature in this field among pregnant women. Our key findings were that pregnant women spend at least half of their time in sedentary activities, which is similar to time reported in children, young people, adults and older adults in the UK (6). Whether sedentary behaviours impact on pregnancy outcomes was less clear-cut with inconsistencies in the literature.

Our review highlights the considerable heterogeneity in the definitions of sedentary behaviours and the methods used to assess this. Differences in the reported prevalence of sedentary behaviours between studies could be due to the unclear definition of sedentary behaviours, or classification of sedentary. For example, one study used a pedometer, an objective method, to classify women as sedentary, considering less than 5000 steps per day as a sedentary lifestyle (30), meanwhile in another study women were considered sedentary if they answered "Reading, watching television, or pursuing some other sedentary occupation", as the most appropriate description of their activities during pregnancy (35). Many of included studies defined sedentary behaviours as activities expending the same or less than one metabolic equivalent (39, 41), however there is no consensus in how many hours per day spent in sedentary behaviours are sufficient to be categorised as sedentary, making it difficult to determine the prevalence of sedentarism. In addition sedentary behaviours were often assessed retrospectively (32, 35), potentially introducing recall bias.

Studies also differed in the assessment measures to calculate sedentary behaviours making comparisons difficult. This corresponds with what has been exposed regarding sedentary behaviours assessment in other populations (6).

Half of the identified studies considered whether sedentary behaviour in pregnancy impacted on maternal or offspring outcomes. This is an important consideration as interventions based on increasing physical activity among obese pregnant women have had limited impact on pregnancy outcomes (49, 52-55). One study found that reducing time spent in sedentary activity was associated with lower gestational weight gain (30). Two other studies, including a large study of >1000 women found no associations with gestational weight gain (12, 40). Likewise there were discrepancies in studies examining associations of sedentary behaviours with hypertensive disorders (34, 44, 46). Notably the one study which found a significant association was classified as poor quality, which decreases the reliability of the result (46). Differences in ethnicity between the study populations may partly explain the discrepant findings with gestational weight gain (one study developed in Denmark, other included only Latin-American pregnant women, and one was developed in China) and hypertensive disorders (one included only Latin-American women, one was developed in the USA and one in China). No association was found between depression and sedentary behaviours, however the one study focusing on that was classified as poor quality (45). None of the studies reported associations between sedentary behaviour and glucose metabolism, as assessed by fasting glucose levels (44, 49), insulin sensitivity (measured using an oral glucose tolerance test) (47), gestational diabetes mellitus (GDM) (49) and in a large study of >1000 women glucose tolerance measured during a glucose tolerance test (36). In contrast, two studies found associations between higher CRP levels and increased sedentary behaviour (10, 44), and one found an association with blood lipids (44) suggesting there may be subtle beneficial effects on maternal metabolism if time spent sedentary is reduced. Overall, there was some suggestion that sedentary behaviours may impact on size at birth (31, 39, 49), but not timing of delivery (12, 31). However, the largest study including over 11,000 pregnant women and which reported associations of sedentary behaviour with birthweight but not gestational length or risk of preterm birth, assessed sedentary behaviours during pregnancy using a postal questionnaire using the question “Are/were you mostly sitting?” (31).

Strengths and limitations

The strengths of this review include the systematic and comprehensive review process which was followed in line with PRISMA guidelines. Two researchers independently assessed eligibility of the titles, abstracts and full-text studies, extracted the data and assessed the articles for bias.

A further strength of the review is that many of the studies were of considerable sample size. Eleven studies included samples of over 1000 women (29, 34, 36, 37, 40, 42, 43), including two assessing more than 4000 women using validated questionnaires (32, 35). Nevertheless, larger studies using objective assessments of sedentary behaviour in pregnancy would considerably add to the literature in this field.

There are also some potential limitations. Though we used a robust search strategy developed from other systematic reviews of sedentary behaviour in the general population (2, 56, 57), it is possible that some potentially eligible studies may not have been identified. For example, some studies appraise sedentary behaviours when assessing physical activity, but the titles do not mention the key words we chose to identify sedentary behaviours. We included a search of reference lists of all papers that the full text was read, to identify any further additional papers.

A limitation of the data is that only two of the identified studies were trials, all the rest were observational. Of the trials, just one used an objective method to assess sedentary behaviours, the other employed a questionnaire. Of the 24 observational studies, only 12 used objective instruments, the other 12 utilised self-reported methods to assess sedentary behaviours. Most of these studies were considered of intermediate quality due to the small sample size, or lack of use of a validated questionnaire or objective measurement. Therefore, the use of objective methods, such as accelerometers, or the combination of movement and physiological (e.g. heart rate) devices should be encouraged if we wish to provide a more clear, realistic, and objective estimate of time spent in sedentary behaviours. Also, the cut-offs used for defining sedentary behaviours as to categorise people as sedentary are not clear and differ between studies, and should be standardised.

Although three studies (11.5%) were classified as poor quality one of these (37) did not report any maternal or infant outcomes and so will not have influenced our interpretation of the literature. As noted the findings of the other two poor quality rated studies (45, 46) should be interpreted with caution. The rest of the studies were classified at least as intermediate quality, mostly because the designs were less reliable (not randomised controlled trials), most of the sample size were small, some utilised non-objective assessment methods, and/or were not validated, but we are confident that they are representative of the available literature.

Conclusions

The observation that pregnant women spend much of their time in sedentary activities opens new approaches aiming to improve pregnant women's health. However our review has identified important gaps in our understanding in this field. For example only two studies considered sleeping time during pregnancy (8, 38) which may be an important consideration when assessing sedentary behaviour due to changing sleep patterns in pregnancy. Further, only one study assessed the transitions from sit/lay to stand, or breaks during sedentary time (8), which may be an important area to target in future interventions studies.

Our review highlights a high prevalence of sedentarism and significant time spent in sedentary behaviours, also that changes in sedentary behaviour may impact on pregnancy outcomes for both mother and child, emphasising this as an area for future mechanistic and intervention studies. However, the heterogeneity in the literature suggests future studies should use robust methodology, preferably with objective measures for quantifying sedentary behaviour.

List of abbreviations

MOOSE: Meta-analysis of Observational Studies in Epidemiology.

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses.

CF: Caterina Fazzi.

KL: Kathryn Linton.

MeSH: Medical subject headings.

GRADE: Grading of Recommendations Assessment Development and Evaluation.

CRP: C-reactive protein.

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Figures, tables, additional files

Figure 1. Search strategy flow diagram.

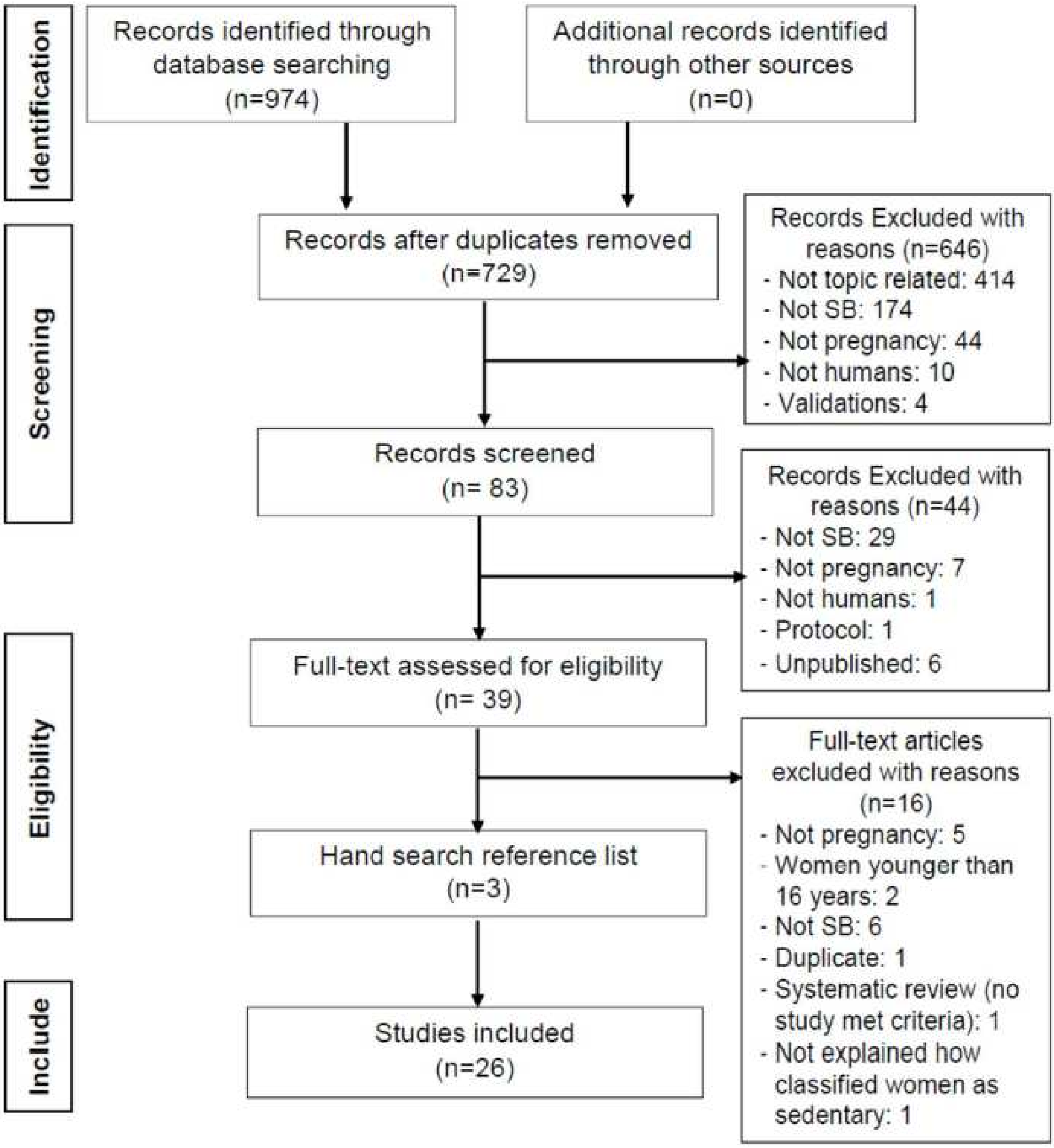


Table 1. Description of included studies (arranged alphabetically).

Table 1 Description of included studies (arranged alphabetically)

Author	Country	Number of participants	Study design	Criteria for inclusion	Assessment method		Definition of sedentary	Quality
Both, et al. (2010) [31]	UK	11759	Cohort	Pregnant women due to deliver between April 1st 1991 and December 31st 1992.	Self-reported questionnaire.	Non-objective.	Who declared being mostly sitting.	Intermediate
Chasan-Taber, et al. (2014) [40]	USA	1276	Cohort	Women of Puerto Rican or Dominican Republic heritage.	Modified version of the Pregnancy Physical Activity Questionnaire (PPAQ).	Non-objective.	Activities expending <1.5 METs.	Intermediate
Chasan-Taber, et al. (2015) [34]	USA	1240	Cohort	Women of Puerto Rico or Dominican Republic heritage.	PPAQ.	Non-objective.	The sum of the MET-h/day spent watching TV/videos or sitting/standing at home, work, or during transportation.	Intermediate
Di Fabio, et al. (2015) [8]	USA	46	Cohort	Healthy pregnant women, including women between 18 and 45 years of age and singleton pregnancy.	- 7 day record diary. - SenseWear® Mini armband accelerometer. - ActivPAL™ Multi-sensor accelerometer.	- Non-objective. - Objective. - Non-objective.	Activities expending ≤1.5 METs (independent of nighttime sleep).	Intermediate
Evenson, et al. (2010) [37]	USA	1280	Cohort	Pregnant women ≥16 years of age.	The Behavioral Risk Factor Surveillance System (BRFSS).	Non-objective.	Two questions on TV watching and computer usage outside of work hours were used as SB indicators. Women were also asked if they were 'mostly sitting' during their usual daily activities.	Poor
Evenson, et al. (2011) [11]	USA	359	Cross-sectional	Pregnant women ≥16 years.	ActiGraph accelerometer.	Objective.	Activities expending <100 counts per minute.	Intermediate
Gollenberg, et al. (2010) [36]	USA	1006	Cohort	Latina ethnicity, age 16–40 years old, singleton pregnancy, and no prior participation in the study.	Modified version of the Kaiser Physical Activity Survey (KPAS).	Non-objective.	Hours spent TV watching per day and frequency of sitting at work.	Intermediate
Gradmark, et al. (2011) [47]	Sweden	101	Cross-sectional	Normal weight and overweight women without diabetes were studied.	Actiheart monitor.	Objective.	Epochs with valid heart rate data and zero accelerometry counts/min.	Intermediate
Hawkins, et al. (2014 Im.) [48]	USA	260	Randomized controlled trial	Women in their first trimester of pregnancy, between 16 and 40 years old, and at high risk for GDM.	Pregnancy Physical Activity Questionnaire (PPAQ).	Non-objective.	The amount of time spent watching TV or videos, or sitting or standing at home, work, or during transportation.	Good
Hawkins, et al. (2014 PA) [10]	USA	294	Cross-sectional	Women in the 2003–2006 NHANES study cycles who self-reported currently being pregnant, were 16 year or older, and who had available data on C reactive protein, physical activity, and SB.	ActiGraph accelerometer.	Objective.	Activities expending <100 counts per minute.	Intermediate
	UK	183				- Objective.		Good

Table 1 Description of included studies (arranged alphabetically) *(Continued)*

Hayes, et al. (2014) [49]			Randomized controlled trial	All obese (BMI ≥ 30 K/m^2) pregnant women.	- Acti-Graph accelerometer.		- Accelerometry: any minute with ≤100 counts/min.	
					- Recent Physical Activity Questionnaire (RPAQ).	- Non-objective.	- RPAQ, minutes spent on activities <1.5 MET.	
Hegaard, et al. (2010) [32]	Denmark	4558	Cohort	Danish-speaking pregnant women.	Self-reported questionnaires.	Non-objective.	Those who chose "mostly sitting" to describe most correctly her level of leisuretime activity.	Intermediate
Hegaard, et al. (2011) [35]	Denmark	4718	Cohort	Age ≥ 18 years, Danish speaking, singleton pregnancy, and intended spontaneous vaginal delivery.	Self-administered questionnaire.	Non-objective.	Those who answered: "Reading, watching television, or pursuing some other sedentary occupation", as the most appropriate description of her activities.	Intermediate
Hjorth, et al. (2012) [9]	Ethiopia	304	Cross-sectional	All pregnant women who attended routine visits at the antenatal care clinic.	- Actiheart (heart rate and movement device).	- Objective.	Energy expenditure ≤1.5 METs.	Intermediate
					- 24 h physical activity recall.	- Non-objective.		
Jiang, et al. (2012) [30]	China	862	Cohort	Pregnant women over 20 years old in a singleton pregnancy, and had no disease including gestational diabetes (GD), hypertension, heart disease, chronic renal disease, and other diseases restricting physical activity.	Pedometer.	Objective.	Less than 5000 steps per day.	Intermediate
Kamareswaran, et al. (2013) [41]	UK	10	Cohort	Type 1 diabetes, current insulin pump therapy, and a viable singleton pregnancy.	Actiheart (heart rate and movement device).	Objective.	Activities expending ≤1 MET.	Intermediate
Li & Zhao (2007) [46]	China	405	Cross-sectional	Pregnant women working in a sewing factory.	Self-reported questionnaire.	Non-Objective.	According to the job, women were assigned to the study group (persistent sedentary) or control group.	Poor
Loprinzi, et al. (2013) [44]	USA	206	Cross-sectional	All women who answered the 2003–2006 National Health and Examination Survey.	ActiGraph accelerometer.	Objective.	Activity counts between 0 and 99 counts/min.	Intermediate
Lynch, et al. (2012) [43]	USA	1355	Cohort	Women from the ambulatory obstetric practices at ≤20 weeks of gestation.	PPAQ.	Non-objective.	The amount of time spent watching TV or videos, or sitting or standing at home, work, or during transportation.	Intermediate
Oken, et al. (2006) [29]	USA	1581	Cohort	Women attending initial prenatal visit, who delivered live infants.	Modified version of the leisure time activity section of the Physical Activity Scale for the Elderly (PASE).	Non-objective.	Hours per week spent watching TV or videos.	Intermediate

Table 1 Description of included studies (arranged alphabetically) *(Continued)*

Padmapriya, et al. (2015) [42]	Singapore	1171	Cohort	Pregnant women aged 18 years and above attending first trimester antenatal dating ultrasound scan clinics.	Interview questionnaire.	Non-objective.	Hours spent on sitting plus hours spent on watching TV per day.	Intermediate
Reid, et al. (2014) [39]	Northern Ireland	100	Cohort	Healthy women, ≥16 years old, with singleton pregnancies, between 26 and 37 week gestation.	Body-media SenseWear Pro3 armband.	Objective.	Activities expending ≤1 MET.	Intermediate
Rhodes, et al. (2014) [33]	Canada	157	Cohort	The cohorts were couples without children, first-time parents during the first year of their parenthood experience, and second time parents during the first year of this parenting experience between the ages of 25 and 40 years of age.	GT1M Activity Monitor (accelerometer and stepcounter).	Objective.	Activities expending 0–100 average acceleration counts/min.	Intermediate
Ruifrok, et al. (2014) [12]	Netherlands	111	Cohort	Healthy pregnant women. Trial 1: nulliparous pregnant women without BMI restrictions, able to read, write and speak Dutch, and within their first 14 weeks of pregnancy; Trial 2: overweight and obese pregnant women at risk for gestational diabetes.	ActiTrainer accelerometer (Acti-Graph).	Objective.	Activities expending <100 counts/min.	Intermediate
Van Raaij, et al. (1990) [38]	Netherlands	18	Cohort	Healthy women judged by medical histories, blood pressure, hemoglobin concentration, and urine analysis.	- Open-circuit indirect calorimetry. - Physical activity diaries.	- Objective. - Non-objective.	Lying, sitting quietly or very light sitting activity, or light-to-moderate sitting activity.	Intermediate
Watts, et al. (2013) [45]	Australia	81	Cross-sectional	Pregnant women regardless of their pregnancy trimester.	The Australian Women's Activity Survey (AWAS).	Non-objective.	Frequency and duration of sitting behavior.	Poor

Table 2. Characteristics of included studies

	Number of studies	Participants (N)
Assessment tool		
Accelerometer	7	1356
Accelerometer and HR sensor	3	415
Pedometer	1	862
Other objective	2	118
Pregnancy Physical Activity Questionnaire (PPAQ)	4	4131
Other self-reported	9	26559

Table 3. Time and proportion of time spent in sedentary behaviours.

	Studies	N	Mean or median (SD or SE or IQR)
Time spent in SB (objective)			
Time spent in SB (h/day)	Ruifrok 2014 [12]	111	8.6 (SD 2.86)
	Hawkins 2014 [10]	294	9.2 (SE 16.2)*
	Loprinzi 2013 [44]	206	7.7 (SE 0.2)*
	Hjorth 2012 [9]	304	18.3* (IQR16.65-19.6)
	Evenson 2011 [11]	359	7.07 (SE 0.165)*
	Di Fabio 2015 [8]	46	12.65 (SD 1.95)*
Sitting quietly or very light sitting activities (h/day)	Van Raaij 1990 [38]	18	6.7(SD1.6)*
Light to moderate sitting activities (h/day)	Van Raaij 1990 [38]	18	1.6(SD1.1)*
Sit/lie time (h/day)	Di Fabio 2015 [8]	46	18.2 (IQR17.1-19)w18; 18.3 (IQR17.6-19.4)w35
Time spent in SB (non-objective)			
Television time (h/day)	Padmapriya 2015 [42]	1171	2.4 (SD1.5)*
Total sitting time (h/day)	Padmapriya 2015 [42)	1171	8.6 (SD3.3)*
Proportion of time spent in SB (objective)			
% of day spent in SB	Hjorth 2012 [9]	304	76.4% (IQR 69.37-81.6*)
% of wear time spent in SB	Ruifrok 2014 [12]	111	65%
	Evenson 2011 [11]	359	57.1% (SE 0.77)
	Hawkins 2014 [10]	294	64.4% (SE 0.02)*
% of time awake in SB	Di Fabio 2015 [8]	46	76% (SD11)w18- 78% (SD13)w35
% of day time in sit/lie	Di Fabio 2015 [8]	46	76% (IQR71-79)w18; 76% (IQR73-81)w35

Footnotes:* Numbers were calculated as means and converted to the same units.

Table 4. Prevalence of sedentarism among pregnant women

Sedentary activity definition	Studies	Assessment method	N	Prevalence
Sedentary	Jiang 2012 [30]	Objective	862	18%
	Hegaard 2011 [35]	Non-objective	4718	29%
Watching TV or videos 5 or more (h/day)	Evenson 2011 [11]	Non-objective	359	15.3%
Watching TV 2 or more (h/day)	Oken 2006 [29]	Non-objective	1581	34%
Watching TV 3 or more (h/day)	Padmapriya 2015 [42]	Non-objective	1171	31.9%
Mostly sitting during day	Evenson 2011 [11]	Non-objective	359	24%

Table 5. Associations between sedentary behaviours and maternal health outcomes.

	Author	Participants	Association (Yes/No)
Pregnancy Outcomes			
GWG	Ruifrok 2014 [12]	111	No
	Chasan-Taber 2014 [40]	1276	No
	Jiang 2012 [30]	862	Yes* (p<0.001)
Hypertensive disorders	Chasan-Taber 2015 [34]	1240	No
	Loprinzi 2013 [42]	206	No
	Li 2007 [46]	405	Yes† (p<0.05)
Depression	Watts 2013 [45]	81	No
Metabolic Outcomes			
Glucose levels	Loprinzi 2013 [44]	206	Trend (p=0.06)
	Hayes 2014 [49]	183	No
Insulin sensitivity	Gradmark 2011 [47]	101	No
GDM	Hayes 2014 [49]	183	No
AGT	Gollenberg 2010 [36]	1006	No
CRP	Loprinzi 2013 [44]	206	Yes‡ (p<0.05)
	Hawkins 2014 [10]	294	Yes‡ (p<0.05)
Blood lipids levels (Total Cholesterol, HDL-cholesterol and triglycerides)	Loprinzi 2013 [44]	206	Yes§ (LDL p<0.05)
Infant outcomes			
Birth Weight	Ruifrok 2014 [12]	111	No
	Hegaard 2010 [32]	4558	No
	Both 2010 [31]	11759	Yes‖ (p<0.05)
Macrosomia	Reid 2014 [39]	100	Yes¶ (p<0.05)
New-born abdominal circumference	Hayes 2014 [49]	183	Yes# (p<0.05)
Gestational length	Ruifrok 2014 [12]	111	No
	Both 2010 [31]	11759	No
Risk of preterm delivery	Both 2010 [31]	11759	No

Footnotes: * GWG was higher in the sedentary group compared with the active group, † the sedentary group developed more hypertension, ‡ Increased time in sedentary behaviours is associated with higher levels of CRP, § increased time in sedentary behaviour is associated with higher LDL cholesterol, ‖ Increased time in sedentary behaviour is associated with lower birth weight, ¶ women delivering macrosomic infants had higher levels of SB, # the association between SB and new-born abdominal circumference was inverse at baseline, and positive at 36 weeks.

Additional File 1. Database search strategy.

Ovid MEDLINE (R) 1946 to October Week 3 2015			
#	**Searches**	**Results**	**Search Type**
1	Pregnant women (MeSH)	5528	Advanced
2	Pregnancy (MeSH)	733929	Advanced
3	Prenatal care (MeSH)	21779	Advanced
4	Sedentary lifestyle (MeSH)	4043	Advanced
5	pregnan* OR gestation* OR gravid* OR antenatal OR prenatal (keywords)	235431	Advanced
6	sedentar* OR sitting OR television OR screen-based OR TV OR watching OR viewing (keywords)	12222	Advanced
7	1 OR 2 OR 3 OR 5	759044	Advanced
8	4 OR 6	14885	Advanced
9	7 AND 8	**235**	Advanced

EMBASE 1980 to 2015 Week 42			
#	**Searches**	**Results**	**Search Type**
1	Pregnant woman (MeSH)	41562	Advanced
2	Pregnancy (MeSH)	549150	Advanced
3	Prenatal care (MeSH)	29123	Advanced
4	Prenatal period (MeSH)	7605	Advanced
5	Sedentary lifestyle MeSH)	6776	Advanced
6	pregnan* OR gestation* OR gravid* OR antenatal OR prenatal (keywords)	282991	Advanced
7	sedentar* OR sitting OR television OR screen-based OR TV OR watching OR viewing (keywords)	14853	Advanced
8	1 OR 2 OR 3 OR 4 OR 6	667010	Advanced
9	5 OR 7	20121	Advanced
10	8 AND 9	**285**	Advanced

Web of Science 30-10-2015		
#	**Search**	**Results**
1	TI= (pregnan* OR gestation* OR gravid* OR antenatal OR prenatal)	
2	TI= (sedentar* OR sitting OR television OR screen-based OR TV OR watching OR viewing)	
3	2 AND 1	**406**

CINAHL 30-10-2015		
#	**Search**	**Results**
1	TI (pregnan* OR gestation* OR gravid* OR antenatal OR prenatal) AND TI (sedentar* OR sitting OR television OR screen-based OR TV OR watching OR viewing)	**39**

SPORTDiscus 22-10-2015		
#	**Search**	**Results**
1	TI (pregnan* OR gestation* OR gravid* OR antenatal OR prenatal) AND TI (sedentar* OR sitting OR television OR screen-based OR TV OR watching OR viewing)	**9**

2.2.2. Conclusion

In this systematic review of the literature 26 published papers were identified that met the pre-specified inclusion criteria. Among the main observations were that pregnant women spend more than the half of their waking time on sedentary activities, and there was some evidence that increased time sedentary during pregnancy might be associated with higher levels of CRP, LDL Cholesterol, babies with larger waist circumferences, and higher numbers of macrosomic babies. The main limitations included a lack of high quality studies looking at sedentary behaviour during pregnancy. In addition, a lack of consensus on the definitions of sedentary behaviour, as well as diverse range of methods to assess sedentary behaviour, were observed.

Notably, in this review we aimed to capture data on sedentary behaviour and pregnant women in general, such that specific data related with morbidly obese pregnant women would be also identified by the search strategy. One study included only obese pregnant women, no study looked at very severely obese women. Overall, eight studies mentioned the means of the BMI of women included, which ranged between 20.2 and 29.2 kg/m^2, only one specified the range of BMI. Twelve studies classified women according to the nutritional status based on BMI, however only two studies looked at the association between sedentary behaviour and nutritional status, finding no associations, however one study suggested that it might be useful to look at the link between the different BMI categories, and sedentary behaviour separately. All in all, limited knowledge has been reported on the literature regarding the association between sedentary behaviour during pregnancy and BMI.

Given this lack of knowledge we investigated in Chapter IV whether there were differences in time spent sedentary in a cohort of very severely obese and lean pregnant women.

2.3. Systematic review update from October 2015 to April 2018

2.3.1. Findings

An update of the systematic review was conducted, in order to find new publications published up until April 2018 meeting the same inclusion criteria when the last literature search was performed.

Eighteen studies met the inclusion criteria. Of these two were randomised controlled trials (Huberty JL, Buman MP, Leiferman JA, Bushar J, & Adams MA, 2016; Huberty JL et al., 2017), five cohort studies (Anjana RM et al., 2016; Nayak M et al., 2016; Padmapriya N et al., 2017; Padmapriya N et al., 2016; Watson ED, Van Poppel MNM, Jones RA, Norris SA, & Micklesfield LK, 2017), four case-control studies (Agopian AJ et al., 2017; Lee LJ et al., 2016; Nasiri-Amiri F, Bakhtiari A, Faramarzi M, Rad HA, & Pasha H, 2016; Spracklen CN et al., 2016), and the seven remaining were cross-sectional studies (de Wit L et al., 2015; Duncan MJ et al., 2017; Hawkins M, Kim Y, Gabriel KP, Rockette-Wagner BJ, & Chasan-Taber L, 2017; Leng J et al., 2016; Sobierajski FM et al., 2018; Tinius RA, Cahill AG, Strand EA, & Cade WT, 2016; Xu X et al., 2018). The distribution of study designs was similar to the published review, except for case-control studies, which were not present before.

As with the original systematic review, most studies were carried out in the USA (n=7) (Agopian AJ et al., 2017; Hawkins M et al., 2017; Huberty JL et al., 2016; Huberty JL et al., 2017; Lee LJ et al., 2016; Spracklen CN et al., 2016; Tinius RA et al., 2016), but there were also studies conducted in Singapore (n=2) (Padmapriya N et al., 2017; Padmapriya N et al., 2016), China (n=2) (Leng J et al., 2016; Xu X et al., 2018), Canada (n=1) (Sobierajski FM et al., 2018), India (n=1) (Anjana RM et al., 2016), Iran (n=1) (Nasiri-Amiri F et al., 2016), South Africa (n=1) (Watson ED et al., 2017), the Netherlands (n=1) (Nayak M et al., 2016), Portugal (n=1) (Duncan MJ et al., 2017), and one involving European pregnant women from Austria, Belgium, Ireland, Italy, Poland, Spain and Netherland (de Wit L et al., 2015), indicating that new countries are starting to look at sedentary behaviour among pregnant women. Most studies involved pregnant women at any stage of gestation (Agopian AJ et al., 2017; Hawkins M et al., 2017; Lee LJ et al., 2016; Nasiri-Amiri F et al., 2016; Padmapriya N et al., 2017; Padmapriya N et al., 2016; Spracklen CN et al., 2016; Tinius RA et al., 2016; Xu X et al., 2018). The rest of the studies looked at different stages of pregnancy. One included pregnant women of 12 or less weeks of gestation (Leng J et al., 2016), one less than 14 (Watson ED et al., 2017), one less than 15 (Nayak M et al., 2016), one less than 20 (de Wit L et al., 2015), one less than 28 (Anjana RM et al., 2016), one within the first and second trimester (Duncan MJ et al., 2017), two between eight and 16 weeks of gestation (Huberty JL et al., 2016; Huberty JL et al., 2017), and one between 26 and 40 weeks of gestation (Sobierajski FM et al., 2018).

One study included pregnant and non-pregnant women in the analysis (non-pregnant women were considered for the comparisons between the two groups) (Hawkins M et al., 2017). One study included only primiparous pregnant women (Spracklen CN et al., 2016), and the remaining studies included either primiparous or multiparous pregnant women. One study included overweight or obese pregnant women (Nayak M et al., 2016), two studies were conducted only with obese pregnant women (de

Wit L et al., 2015; Tinius RA et al., 2016), and two studies involved only inactive women (not meeting the 2008 Physical Activity Guidelines Advisory Committee Report ("Physical Activity Guidelines Advisory Committee report, 2008. To the Secretary of Health and Human Services. Part A: executive summary," 2009)) (Huberty JL et al., 2016; Huberty JL et al., 2017). Two studies used mothers' activity at workplace in the analyses (Agopian AJ et al., 2017; Lee LJ et al., 2016). Eight studies employed objective devices to assess sedentary behaviour (accelerometers and activity monitors), and 10 studies utilised non-objective methods (**Table 3**). Of these, two used a Computer Assisted Telephone Interview (Lee LJ et al., 2016; Spracklen CN et al., 2016), two used an interviewer-administered questionnaire (Padmapriya N et al., 2017; Padmapriya N et al., 2016), one used the GPAQ (Watson ED et al., 2017), one based the occupational behaviour on an occupational report in the birth certificate (Agopian AJ et al., 2017), one used the Madras Diabetes Research Foundation-Physical Activity Questionnaire pregnancy version (MPAQ-Pregnancy) (Anjana RM et al., 2016), one used the PPAQ (Nasiri-Amiri F et al., 2016), one employed a self-administered questionnaire, which was validated according to the authors (Leng J et al., 2016), and one administered a survey by trained medical students (Xu X et al., 2018). The MPAQ-Pregnancy has been adapted from the MPAQ and the reproducibility was scored as good, the GPAQ, MPAQ, and the PPAQ have been validated, as reported by the authors.

Table 3. Characteristics of included studies

	Number of studies	Participants (N)
Assessment tool		
Accelerometer	6	605
Activity monitor	2	160
Self-reported	8	18,097
Database	2	9,592

2.3.1.1. Amount and proportion of time spent in sedentary behaviour

The amount of time spent sedentary was assessed in nine studies, using objective (de Wit L et al., 2015; Duncan MJ et al., 2017; Hawkins M et al., 2017; Huberty JL et al., 2016; Huberty JL et al., 2017; Nayak M et al., 2016; Tinius RA et al., 2016), and non-objective (Anjana RM et al., 2016; Watson ED et al., 2017; Xu X et al., 2018) methods (**Table 3**). Two studies used the same data, but performed different analyses, therefore regarding the amount of sedentary behaviour, the same values are shown (Huberty JL et al., 2016; Huberty JL et al., 2017). Overall, sedentary time varied from 5.3 hours (total sitting time) to 17.6 hours during waking time, per day (Duncan MJ et al., 2017). Different and new sedentary activities were observed in this updating, for instance mobile phone usage was added as a new screen time activity, which makes sense as it might be a predominant sedentary activity nowadays. Regarding the proportion of time spent sedentary we observed a range between 57.3% and 67.5%, both assessed using an accelerometer, which on average seems to be lesser than what we observed in the previous review, which might be due to the increased number of studies reporting that variable (**Table 4**).

Table 4. Time and proportion of time spent in sedentary behaviour

	Studies	N	Mean (SD or SE) or median (IQR)
Time spent in SB (objective)			
Time spent in SB (h/day)	Duncan 2017	137	17.6 (SD 0.5)*
	Huberty 2016,17	80	16.3 (SD 2.9)*
	de Wit 2015	98	8.1 (SD 0.4)*
	Hawkins 2017	234	8.0 (IQR 7.6-7.8)*
	Nayak 2016	46	7.3 (SE 1.2)*
Time spent in SB (non-objective)			
Sedentary time (h/day)	Anjana 2016	795	12.6 (IQR 2.01)*
Television time (h/day)	Anjana 2016	795	3.0 (IQR 2.9)*
	Xu 2018	2,345	1.8 (SD 1.7)
Computer viewing (h/day)	Xu 2018	2,345	1.7 (SD 2.3)
Mobile viewing (h/day)	Xu 2018	2,345	2.4 (SD 2.2)
Total screen time (h/day)	Xu 2018	2,345	5.9 (SD 3.7)
Total sitting time (h/day)	Watson 2017	256	5.3 (IQR 3-8)*
Proportion of time spent in SB (objective)			
% of day spent in SB	Sobierajski 2018	58	67.5% (SD 7.9)
% of time awake in SB	Hawkins 2017	234	57.3% (IQR55.4-59.2)
% of day spent sitting	Nayak 2016	46	59% (SD 8.2)*

Footnotes:*Numbers were calculated as means and/or converted to the same units.

2.3.1.2. Definitions of sedentary behaviour

The authors of the two studies using the same data reported the absence of a precise definition of sedentary category by the active monitor (Fitbit™) manufacturer, although they defined sedentary behaviour as seated activities at ≤1.5 METs. Besides it is not clear whether authors included sleeping time or not in the final amount, as it is not specifically reported, and participants were instructed to wear the activity monitor for 24 hours daily (Huberty JL et al., 2016; Huberty JL et al., 2017). In two studies carried out in Singapore, the authors estimated sedentary behaviour based on total sitting time per day and television viewing time per day (Padmapriya N et al., 2017; Padmapriya N et al., 2016). Sedentary behaviour was defined as sitting time per day (Leng J et al., 2016; Spracklen CN et al., 2016; Watson ED et al., 2017). In another study, the authors estimated sedentary time including television viewing time, computer usage time, and mobile phone viewing time (Xu X et al., 2018). The study which used the PPAQ, defined sedentary behaviour as all activities spending 1.5 METs or less (Nasiri-Amiri F et al., 2016). The two studies looking at occupational activities defined sedentary as sitting at work (Agopian AJ et al., 2017; Lee LJ et al., 2016).

In the study carried out in India, women were classified as sedentary if their physical activity level cut off was between 1.40 and 1.69, according to the score calculated using the MPAQ pregnancy version guideline, which calculates the score based on type, intensity, duration, and frequency, for each of the four different activity domains (work, transport, recreation and daily living general activities) (Anjana RM et al., 2016).

The studies employing accelerometers to assess sedentary behaviour defined sedentary behaviour as less than 100 counts per minute (de Wit L et al., 2015; Duncan MJ et al., 2017; Hawkins M et al., 2017; Nayak M et al., 2016; Sobierajski FM et al., 2018; Tinius RA et al., 2016).

2.3.1.3. Prevalence of sedentarism among pregnant women (**Table 5**)

When looking at the prevalence of sedentary behaviour, four studies assessed sedentarism rates among pregnant women. In the study carried out in India using a questionnaire the authors estimated that 86.2% of pregnant women were sedentary (Anjana RM et al., 2016). Meanwhile in China it was observed that 12.5% of pregnant women watched television for more than four hours per day, of these more than 3%

watched longer than six hours per day (Xu X et al., 2018), whilst in the other Chinese study researchers observed that 43.2% of pregnant women were sitting for more than four hours per day (Leng J et al., 2016). In one study with a large population-based sample of mothers of control infants in the National Birth Defects Prevention Study the authors observed that more than 26% of women reported spending at least 75% of the working time sitting (Lee LJ et al., 2016) (**Table 5**).

Table 5. Prevalence of sedentarism among pregnant women

Sedentary activity definition	Studies	Assessment method	N	Prevalence
Sedentary	Anjana 2016	Non-objective	795	86.2%
Watching TV 4 or more (h/day)	Xu 2018	Non-objective	2,345	12.5%*
Sitting at home 4 or more (h/day)	Leng 2016	Non-objective	11,450	43.2%
Computer viewing 4 or more (h/day)	Xu 2018	Non-objective	2,345	16%*
Mobile phone using 4 or more (h/day)	Xu 2018	Non-objective	2,345	21.7%*
Sitting at work ≥ 75%	Lee 2016	Non-objective	6,337	26.4%

*spending 4 to 6 hours and more than 6 hours are in the same amount as more than 4 hours per day.

2.3.1.4. Change in sedentary behaviour during pregnancy

In one study (Huberty JL et al., 2017) sedentary time showed a significant increase over the course of pregnancy, the researchers were looking at the effect of different strategies to promote healthy and/or active life among pregnant women based on text messages sent to the participants' mobile phones. Comparing each strategy with the control arm, which consisted on three texts messages per week including only two physical activity messages across the whole pregnancy, a significant increase on sedentary activity was observed in the two arms including seven text messages per week of which six were on physical activity (Huberty JL et al., 2017).

One study (Watson ED et al., 2017) looked at changes in sedentary behaviour along pregnancy, but did not observe significant differences in sitting time between the second and third trimester of gestation. Throughout pregnancy women spent the majority of the time sedentary on television watching with no significant modification (Watson ED et al., 2017). Similarly, in one study looking at changes on sedentary behaviour between the first and second trimesters, and between week and weekend days, no significant differences were found (Duncan MJ et al., 2017).

In another paper looking at the frequency and level of estimated occupational sedentary behaviour among mothers of control infants in the National Birth Defects Prevention Study, minor changes were observed in levels of sedentary behaviour in different trimesters (Lee LJ et al., 2016).

In the study carried out in India, where the researchers applied a Model of Care strategy for women diagnosed with GDM, which involves education about GDM, suggestions on dietary principles, and management of GDM, plus individualised support about physical activity benefits during pregnancy. An overall decline on sedentary behaviour was observed, of 26% from before to after the intervention (Anjana RM et al., 2016).

In one study looking at the trajectories of objectively-measured sedentary time over the course of pregnancy among inactive women, researchers found that sedentary time increased significantly along gestation, with intensified growths at the end of pregnancy (Huberty JL et al., 2016).

2.3.1.5. Additional factors affecting sedentary lifestyles

Two studies aimed to compare sedentary time between active and inactive women. In the first study conducted in South Africa, active pregnant women spent significantly less time resting during the day and watching television than the inactive women, however no statistically significant differences were observed on sedentary behaviour between active and inactive pregnant women in the third trimester (Watson ED et al., 2017). Among pregnant women in the USA, non-active women showed spending significantly more time sedentary, than active pregnant women, according to the accelerometer data (Tinius RA et al., 2016).

In the only study comparing pregnant and non-pregnant women, it was observed that pregnant women spent more time sedentary than non-pregnant women when using a minimum bout length of one minute (Hawkins M et al., 2017).

In the study with the sample of mothers of control infants in the National Birth Defects Prevention Study, mothers in the “Other” race/ethnicity group and non-Hispanic White mothers were more likely to spend 50% or more of their time sitting, compared to non-Hispanic Black and Hispanic mothers (Lee LJ et al., 2016).

2.3.1.6. Associations between sedentary behaviour and pregnancy outcomes (**Table 6**)

One study focused on the effect of sedentary behaviour on hypertension and preeclampsia during pregnancy. The authors found that the risk of preeclampsia was positively associated with time spent sitting per day. No link was observed between time sedentary and risk of gestational hypertension, however the authors suggested that higher levels of sedentary behaviour improved the odds of gestational hypertension and preeclampsia (Spracklen CN et al., 2016).

Depression symptoms and higher state of anxiety and trait anxiety symptoms were not associated with total sitting time or television viewing time during pregnancy (Padmapriya N et al., 2016). In the study including pregnant women from different European countries, looking at depressed mood and pregnancy-related worries, the authors found no association between those variables and sedentary behaviour (de Wit L et al., 2015).

In another study, the researchers found a positive link between sedentary time with higher levels of HDL and total cholesterol, at 24 weeks of gestation, in cross-sectional analyses. It was also observed an association of increased levels of interleukin 10 and lower levels of interleukin 6, with more sedentary time at 24 weeks of pregnancy, meanwhile at 32 weeks of gestation more sedentary time was associated with increased levels of leptin levels and tumour necrosis factor (all are markers of inflammation). In univariate analyses, comparing by tertiles of sedentary time at 24 weeks of gestation, the upper tertile of sedentary time showed increased levels of LDL and total cholesterol versus the first and second tertiles, and greater levels of HDL compared with the first tertile. Meanwhile, the second and third tertile of sedentary time showed significantly higher levels of leptin compared to the first tertile, at 32 weeks of pregnancy. In the same analyses, when adjusted for maternal age, BMI, and moderate to vigorous physical activity, more sedentary time was linked to lower levels of interleukin 6, at 24 weeks of gestation, and with greater levels of tumour necrosis factor, leptin and interleukin 10, at 32 weeks of gestation (Nayak M et al., 2016).

Three studies looked at the association between sedentary behaviour and GDM. In the study conducted in India, it was observed that those women who did not develop GDM were significantly less sedentary than women who developed GDM (86.2% and 61.2% respectively). Authors reported that after adjusting for age, BMI, previous history of GDM, gestational age at study entry, and cereal staple intake, women in the third tertiles of sedentary behaviour compared to those in the first tertile, had 3.8 times higher risk of adverse outcomes (Anjana RM et al., 2016). In one study carried out in China, the authors found that the risk of developing GDM was significantly increased when sitting for four hours per day compared with sitting for less than two hours per day. Additionally, it was observed that among overweight or obese pregnant women, but also among women with normal weight, the risk of developing GDM was positively associated with levels of sedentary behaviour during pregnancy (Leng J et al., 2016). In one study carried out in Singapore, the authors looked at the association between fasting glucose levels and 2-h postprandial plasma glucose levels with television time and total sitting time during pregnancy. No association was observed overall and by nutritional status groups between fasting glucose levels or 2-h postprandial plasma glucose levels, and television time during pregnancy. Neither between sitting time and 2-h postprandial plasma glucose among overweight or obese women. No association of television viewing and the development of GDM was observed (Padmapriya N et al., 2017).

The study conducted in Canada looked at the association between cardiovagal baroreflex gain and mean arterial pressure with sedentary behaviour in late pregnancy, however not significant association was found between any of those variables and sedentary behaviour (Sobierajski FM et al., 2018).

Table 6. Associations between sedentary behaviour with maternal and infant health outcomes

	Author	Participants	Association (Yes/No)
Pregnancy Outcomes			
Preeclampsia	Spracklen 2016	673	Yes[a]
Gestational hypertension	Spracklen 2016	673	No
Depression symptoms	Padmapriya 2016	1,144	No
Depressed mood	De Wit 2015	98	No
Metabolic Outcomes			
HDL	Nayak 2016	46	Yes[b]
Total cholesterol	Nayak 2016	46	Yes[c]
Interleukin 10	Nayak 2016	46	Yes[d]
Interleukin 6	Nayak 2016	46	Yes[e]
Leptin levels	Nayak 2016	46	Yes[f]
Tumour necrosis factor	Nayak 2016	46	Yes[g]
GDM	Anjana 2016	795	Yes[h]
	Leng 2016	11,450	Yes[i]
	Padmapriya 2017	1,083	No
Infant Outcomes			
Orofacial cleft lip with or without cleft palate	Agopian 2017	3,255	Yes[j]

Footnotes: [a]more time spent sitting per is associated with increased risk of preeclampsia, [b]higher sedentary time is associated with increased levels of HDL at 24 weeks of gestation, [c]higher sedentary time is associated with increased levels of total cholesterol at 24 weeks of gestation, [d]increased time in sedentary behaviour is associated with higher levels of interleukin 10 at 24 weeks of pregnancy, [e] increased time in sedentary behaviour is associated with lower levels of interleukin 6 at 24 weeks of gestation, [f]more sedentary time was associated with increased levels of leptin levels at 32 weeks of gestation, [g]more sedentary time was associated with increased levels of tumour necrosis factor at 32 weeks of pregnancy, [h]women with GDM were significantly more sedentary, [i]sitting for four hours per day is associated with a higher risk of developing GDM, [j]more time spent sitting at work reduce the risk of orofacial cleft lip with or without cleft.

2.3.1.7. Associations between sedentary behaviour and infant outcomes (**Table 6**)

One case-control study analised the relationship between maternal occupational physical activity and risk for orofacial cleft lip with or without cleft palate, finding that more time spent sitting at work was beneficial to prevent cleft lip with or without cleft palate (Agopian AJ et al., 2017). However it is important to highlight that considering that there are 11 cases of cleft lip with or without cleft palate in every 10,000 live births, the association observed in this case-control study probably is not representative for the general pregnant population, and might be due to chance.

2.3.1.8. Quality assessment results

Of the 18 included studies, five were scored as poor quality, 13 scored as itermediate, no studies were scored as good quality. The low scored reported in this review are mostly due to the lack of randomised controlled trials, using reliable methods to assess sedentary behaviour with reasonable large sample sizes.

2.4. Comparisons between reviews

Several differences can be observed between the new updated review including 18 new papers, and 28,303 participants, and the data collated in the previous systematic review. Among the study designs many differences can be observed. In the new review four case-control studies are included, compared with no case-control studies in the first review. When looking at the assessment methods used to estimate sedentary behaviour, comparing objective and non-objetive instruments, no big differences were observed. In the first review half studies had used objective methods to assess, and in the update version 44.4% did, suggesting that no improvements in methodology have been observed over time. With regard to quality, using the same criteria as in the systematic review including papers published until October 2015, the main difference is that no studies scoring good quality were included in the new updated review, compared with two included in the first, and indeed five studies were classified as poor quality (27.8%) in the new review, compared with three (11.5%) in the first review. In both reviews, most were classified as intermediate quality. Two studies included in the new review looked at occupational time, which was not observed in the first review.

The updated findings suggest pregnant women spend more time sedentary than we previously reported, and that the prevalence of sedentarism was higher.

The updated systematic review added new findings that had not been studied in the publications included in 2.1.1. Regarding the maternal outcomes agreement was observed between the two systematic reviews which found no association between sedentary behaviour and depression. No coincidence was observed in any other outcome between the reviews. Interestingly, the association between time sedentary (objectively assessed) and risk of GDM, among a sample size of less than two hundred pregnant women, was not significant in the first review, however the same association was statistically significant in two of the three papers which studied it in the updated review, one using a sample size of over 11 thousand pregnant women, albeit using a non-objective appraisal method to assess sedentary behaviour. Thus suggests that too much time spent sedentary during pregnancy might increase the risk of developing GDM. The definitions to classify pregnant women as sedentary were very diverse in both reviews, and no concordance at all was observed between reviews, i.e. in the first review were classified as "watching TV or videos 5 or more (h/day)", or "Watching TV 2 or more (h/day)", or "Watching TV 3 or more (h/day)", and in the updated version this was "Watching TV 4 or more (h/day)", "Sitting at home 4 or more (h/day)", or "Computer viewing 4 or more (h/day)", or "Mobile phone using 4 or more (h/day)". Interestingly, in the new review mobile phone viewing was included as a sedentary activity, which is probably a sign of updating too, to the actual times.

Table 7. Comparisons between reviews

Variables	Updated review, April 2018	Review Published 2016	Overall
Study design			
Case-control	4 (22.2%)	0 (%)	4 (9%)
Cohort	5 (27.8%)	17 (65.4%)	22 (50%)
Cross-sectional	7 (38.9%)	7 (26.9%)	14 (31.8%)
RCT	2 (11.1%)	2 (7.7%)	4 (9%)
Assessment Method			
Objective	8 (44.4%)	13 (50%)	1 (47.7%)
Non-objective	10 (55.6%)	13 (50%)	23 (52.3%)
Quality			
Good	0 (0%)	2 (7.7%)	2 (4.5%)
Intermediate	13 (72.2%)	21 (80.8%)	34 (77.3%)
Poor	5 (27.8%)	3 (11.5%)	8 (18.2%)
Time sedentary (objective)			
Time spent sedentary (h/day)	17.6-7.3	18.3-7.1	18.0-7.2
Proportion of time spent sedentary (objective)			
% of day sedentary	67.5%	76.4%	71.9%
% of time awake spent sedentary	57.3%	76%	66.6%
Prevalence of Sedentarism			
Sedentary	86.2%	18-29%	54.8%
Maternal outcomes			
Depression	No	No	No
HDL Cholesterol	Yes	No	-
LDL Cholesterol	No	Yes	-
Total Cholesterol	Yes	No	-
GDM	Yes	No	-

2.5. Conclusion

After updating the systematic review including publications studying sedentary behaviour during pregnancy, 18 new papers were found, studying 28,303 pregnant women. In terms of the methods and the quality of the included studies, sismilarities were observed between reviews. Regarding the findings, the main addition of the updated review relays on the confirmation of the lack of association between depression and sedentary behaviour during pregnancy. Contrarily, on the association between GDM and sedentary behaviour during pregnancy, in the first review one paper using a limited sample size assessed that, finding no significant association, whilst in the latter review, of the three studies assessing that association two found a significant positive association, one testing more than 11 thousand pregnant women, meaning that increased time sedentary improves the risk of developing GDM.

Some discrepancies on the prevalence of sedentary behaviour were observed in the first review, which were largely intensified in the updated review, however that perception might be biased due to the many different ways of measuring.

The essential finding from both reviews is that pregnant women spend a huge amount of time sedentary.

Now that we have learnt that pregnant women spend at least seven hours daily on sedentay activities, new questions have emerged: How do pregnant women expend their energy? Do obese pregnant women spend significantly more time sedentary than lean pregnant women? These questions are addressed in Chapter IV.

Chapter III. Clinical Methods

Chapter III. Clinical Methods

3.1. The Antenatal Metabolic Clinic

Obese pregnant women who participated in the studies described in Chapters IV, V and VI were recruited from the Antenatal Metabolic Clinic at the Royal Infirmary of Edinburgh, Edinburgh, UK. The Tommy's Research Centre in Edinburgh opened in 2008, focusing on looking at the risks of obesity during pregnancy, and opened the Tommy's Antenatal Metabolic Clinic, which offers specialist antenatal care for pregnant women with BMI>40, helping around one hundred women per year. At antenatal booking, women who meet the BMI criteria are invited to attend the multidisciplinary clinic. Women who attend the clinic receive their usual antenatal care, plus personalised advice about healthy eating and healthy lifestyles in pregnancy and are reviewed by a specialist dietician for tailored dietary advice. The care also includes regular and frequent monitoring of the mother and baby, and education about the increased risk of complications that obesity causes in pregnancy. Previous studies have revealed that women receive little information about physical activity and sedentary behaviour in pregnancy, have less knowledge about the benefits of physical activity and the adverse effects of sedentary behaviour in pregnancy, but has also highlighted that there are several barriers to taking up any physical activity for women with BMI>40 (Denison FC et al., 2015; Weir Z et al., 2010).

The Antenatal Metabolic Clinic has taken care of more than 1,000 severely obese women throughout their pregnancies since 2008. It has been shown that severely obese pregnant women who attend the clinic have better clinical outcomes than women who do not. When pregnancy outcomes have been compared between 510 women who attended the clinic and 494 women receiving standard antenatal care, even though those in the clinic were at higher risk as they were more obese, women receiving the specialised care provided by the clinic were eight times less likely to have a stillbirth. The rate of stillbirths was two per thousand deliveries, among the clinic participants, which was less than 50% of the rate for Scotland overall (4.7 per 1,000 in 2012), and less than a third of the Scottish average for severely obese women (seven per 1,000), meaning that they are eight times less likely to have a stillbirth than similarly obese women who do not attend the clinic. Other benefits were observed on a lower risk of having a baby of low birthweight (less than 2.5 kg). Importantly, women attending the clinic had more chances of being tested for diabetes, allowing a better, earlier and proper management of the condition when diagnosed (Reynolds RM, Denison FC, & Norman JE, 2016).

3.2. Ethical Approval

Ethical approvals were required first for the cross-sectional study described in Chapter IV, including the data involving energy expenditure using the PPAQ, and accelerometry, was obtained from Lothian NHS Research Ethics Committee (REC reference number 09/S1103/03). Ethical approval was also obtained for the Options in Pregnancy to increase ActiveLy Sitting (OPALS) Study (Chapter VI), by the South East Scotland Research Ethics Committee (REC reference number 17/SS/0101). All participants provided written informed consent.

3.3. Participants

3.3.1. Sample size

In chapter IV, a post-hoc power calculation was conducted using the Sampsize program for comparative study of means. The calculation was performed using mean and standard deviation values, and sample size for each group in early and late pregnancy, for total physical activity (MET-hours/day), and accelerometry average activity counts/minute. The significance level was set at 5% (Mohd Shukri N, 2011).

For chapter V, the intervention design, we intended to test the proposed exercise intervention on up to 30 subjects, or until data saturation (i.e. obtaining the same responses by more than five subjects, for all the exercises).

For the OPALS Study (Chapter VI) a pragmatic decision was made for the sample size, based on time, we decided to recruit as many women as possible until the first week of March, considering timelines to finish the thesis and that the intervention lasted for 12 weeks.

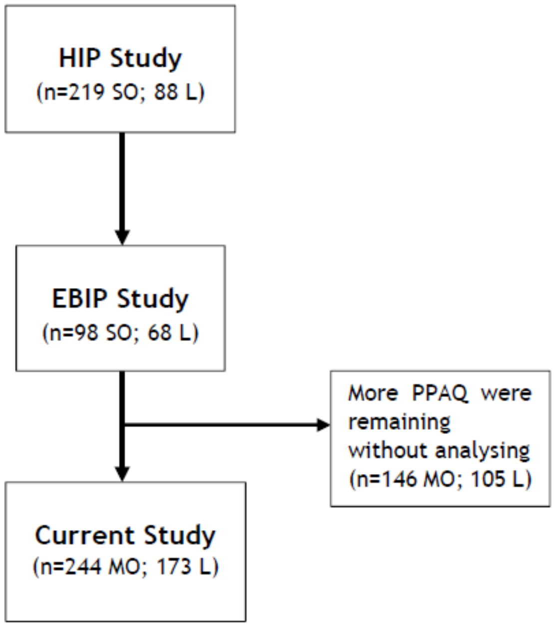
3.3.2. Criteria for inclusion

For the cross-sectional study (Chapter IV), morbidly obese (BMI≥40Kg/m^2) women with a singleton pregnancy attending the Antenatal Metabolic Clinic at the Royal Infirmary of Edinburgh, UK, and lean (BMI ≤25 Kg/m^2) and pregnant women recruited from community antenatal clinics who were participating in a larger study examining the consequences of morbidly obese pregnancy were invited to take part in the study (Forbes S et al., 2015; Mina TH et al., 2015). The PPAQ (Chasan-Taber L et al., 2004) was administered to all recruited women in early (<24 weeks), and late (≥24 weeks) gestation. For the intervention design (Chapter V), women attending the antenatal Metabolic Clinic, BMI equal or over 40 Kg/m^2 were asked to participate in an interview with the researcher, to test the six proposed exercises. For the OPALS Feasibility Study (Chapter VI), midwives at the Antenatal Metabolic Clinic, invited patients, who were pregnant women, BMI 40 Kg/m^2or over, to take part in the intervention, providing them with the Participants Information Sheet. After reading that, the researcher approached the potential participants, asking if they were interested in taking part.

3.3.3. Recruitment

For the energy expenditure assessment (Chapter IV), PPAQ data administered previously for the Energy Balance in Pregnancy (EBIP) Study, and the accelerometer data available from the same study were employed. The EBIP Study has concluded. Women recruited for the EBIP study were those women taking part in the Hormones and Inflammation in Pregnancy (HIP) study who had stated interest in volunteering to be assessed on energy expenditure. The HIP Study has concluded.

Figure 3. Related studies



For the intervention design (Chapter V), initially a physical activity and sedentary behaviour questionnaire was administered. Women attending the Ant

enatal Metabolic Clinic were approached by the midwives who asked them if they were interested in replying a questionnaire, gave the questionnaire, for self-report and collected the questionnaires after words. Later, for the proper intervention design, women were recruited at the Antenatal Metabolic Clinic by the researcher, who approached women in the waiting room, asking them whether or not they were interested in helping to design a physical activity intervention, which involved trying some exercises.

For the OPALS Study (Chapter VI), in the same Metabolic Antenatal Clinic, midwives during their personalised counselling meeting, briefly explained the OPALS study to the patients, and gave them the Information Sheet. The researcher approached then the patients, asking if they were interested in taking part, and all those interested had an interview with the researcher, where the study was explained more in depth and if agreeing to sign the consent, a folder with all materials and information was given to each participant, additionally each exercise was practiced.

3.4. Collection of data

3.4.1. Measurements

3.4.1.1. Anthropometric measures

Anthropometric measures were collected for the cross-sectional study (Chapter IV) by the former researcher, in charge of the EBIP study. Height was measured with SECA 216 stadiometer, during the first visit and 20 week visit for all participants, lean and severely obese. The unit used for the height in the study is metres (m). The weight was measured with SECA 959 chair scale. The unit used to assess weight in this study is kilograms (Kg). GWG was calculated as the difference between weight in Kg measured during the first visit and at the 36 week visit. Body composition and its components (body fat mass, fat-free mass and total body water) were measured by using Tanita TBF-300M body composition analyser, and all results are in percentage, but can be converted to Kg, using the body weight. The BMI was calculated by dividing weight by the squared of the height. Therefore the unit of measure is Kg/m^2.

3.4.1.2. Energy expenditure

For the cross-sectional study (Chapter IV), energy expenditure was estimated using both the PPAQ and the Actical Accelerometer.

Pregnancy Physical Activity Questionnaire (PPAQ) (**Appendix 2**)

The PPAQ is an instrument designed especially for pregnant women to assess the energy spent in activities of different intensities including household or care giving, occupational, sports or exercise, transportation, and sedentary activities. By answering 36 questions, participants report the time spent in 32 activities. Instructions in how to calculate the energy expenditure were provided. According to the instructions, to calculate the energy expenditure each response had assigned a score for duration and for intensity. Then, the score for intensity per each question was multiplied by the score corresponding to time, reaching to a measure of average weekly energy expenditure (METs per hour). Questions were grouped depending on intensity (sedentary, light, moderate, or vigorous), and type of activity (household/care giving, occupational, or sports/exercise), therefore summing all the questions involving the same intensity or type of activity, was obtained the final amount of energy expended per intensity and per type of activity. Likewise, to obtain the amount of total energy expended, was summed all the energy expended in the different intensities. The PPAQ was validated in 2004 against the Actigraph 7164 accelerometer (Manufacturing Technology, Inc., Fort Walton Beach, FL). To have all the energy expenditure results in the same unit, METs were converted into kilocalories, by multiplying the number of METs by the RMR (individually calculated). To calculate RMR the Mifflin and St Jear equation was employed (BMR= 9.99 * Weight) + (6.25 * Height) - (4.92 * Maternal Age) – 161) (Mifflin MD et al., 1990), which according to the literature is considered the best equation to estimate resting energy expenditure in obese and non-obese adults (Frankenfield D, Roth-Yousey L, & Compher C, 2005; Frankenfield DC, Rowe WA, Smith JStanley, & Cooney RN, 2003).

Actical Accelerometer (Mini Mitter Company, Inc., US)

The Actical accelerometer assesses energy expenditure spent in different intensities; a software analyses the data providing data on Active Energy Expenditure (AEE) in kilocalories, and total energy expenditure in Metabolic Equivalents per Time (Crouter SE et al., 2010). The software was designed to estimate energy expenditure by algorithms which were formulated based on validated studies with large samples of participants performing different tests. The software shows data including duration and energy expenditure at each intensity (sedentary, light, moderate and vigorous). The device can be worn on the hip, wrist or ankle. According to the software, sedentary behaviour is classified as time spent performing activities that register less than 100 counts per minute (Wong SL, Colley R, Connor Gorber S, & Tremblay M, 2011).

Women were asked to wear the Actical on their non-dominant wrist. They were also asked to wear it for two weekdays and one weekend day. Instructions were given to wear it for 24 hours for each day, during all waking and sleeping hours. During bathing or while they were doing water sports they had to remove the accelerometer and take note of the time, duration and reason for taking off the device, using a form provided. Accelerometers were set up before collecting data, with all personal information such as subject’s identity, gender, age, height, weight, and the start date and time.

3.4.1.3. Physical Activity and Sedentary behaviour knowledge (Chapter V)

Sedentary behaviour and physical activity questionnaire

For the intervention design (Chapter V) initially a questionnaire (**Appendix 3**) was administered to pregnant women attending the Antenatal Metabolic Clinic, aiming to find out what pregnant women knew regarding physical activity and sedentary behaviour, also the information they received during pregnancy on the same topics, and whether or not they were interested in performing some exercises during pregnancy. The questionnaire was designed by the researcher, and contained 10 questions.

3.4.1.4. Intervention design (Chapter V)

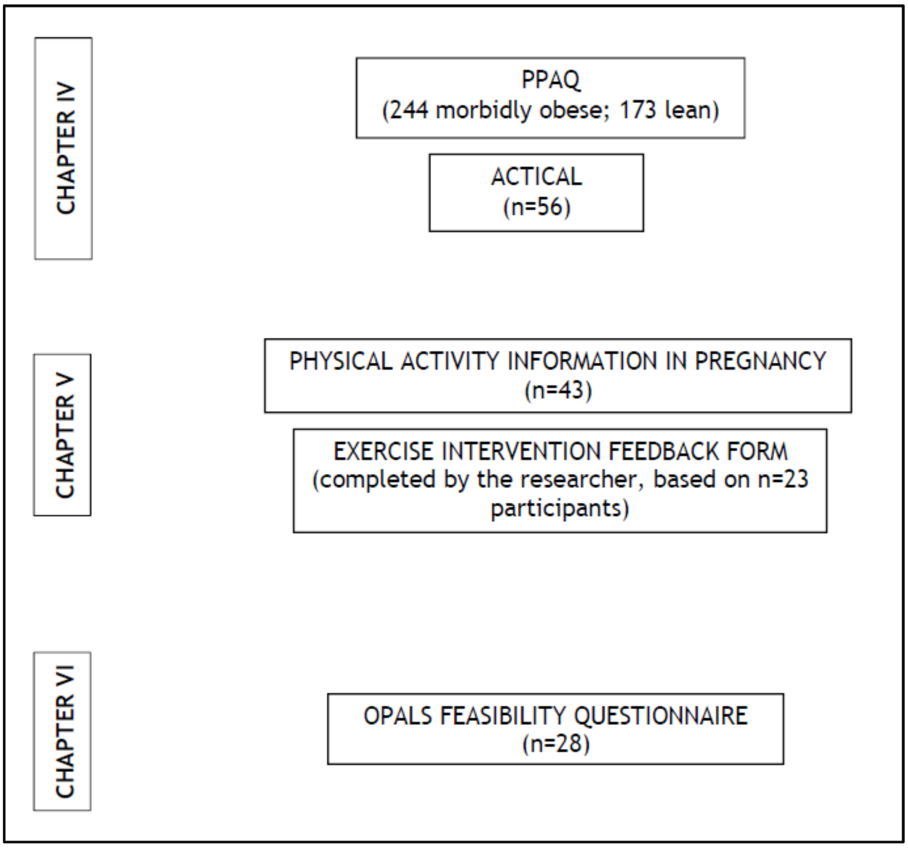
For the design of the exercise intervention, after signing the consent participants tried each of the proposed exercises, to evaluate that a form was designed considering the personal performance, but also if they felt comfortable to do the exercise, the perceived exertion (using the modified Borg Scale 1-10) (Borg G, 1998), and their observations if they had any, for each of the proposed six exercises.

3.4.1.5. OPALS Feasibility Study (Chapter VI)

For the OPALS Feasibility Study, after participants agreed in taking part, a personal meeting was held between the researcher and each of the participants, where the consent was signed by participants and the researcher. After signing the consent, the researcher and the participant performed each exercise at the same time, thence the researcher was able to make the required corrections to the technique, and related advice was given, plus a brief explanation on how to fill the diary. A plastic folder was provided to each participant, containing a new medium size (22 cm diameter) soft ball (deflated and folded), a Participant Information Sheet, a General Practitioner Information Sheet, an Exercise Strategy Guideline, an Exercise Strategy Activity Diary, the participant's copy of the consent, and a laminated Exercise Guideline Summary with magnet.

After the intervention all participants answered a Feasibility Questionnaire specially designed to assess the feasibility of the study (**Appendix 5**).

Figure 4. Measurement instruments



3.5. Data analysis

For the statistical analysis IBM SPSS Statistics 19.0 software was used. For the cross-sectional study (Chapter IV) continuous variables such as GWG, time spent in sedentary behaviour, time spent in different intensities physical activities and total daily energy expenditure, were compared between severely obese and lean pregnant women, and also between women recruited at early and late pregnancy. To determine whether using parametric or non-parametric methods, the Shapiro-Wilk normality test was performed. When the data came from normally distributed samples, we used ANOVA in the analysis, but when the data did not come from normally distributed samples, non-parametric Mann-Whitney U test was used. A descriptive quantitative analysis was conducted to analyse the Sedentary Behaviour and Physical Activity Questionnaire answers, looking at frequency and percentage.

The intervention design (Chapter V) was analysed descriptively, quantitative and qualitatively, in accordance to the questions which were assessed with numbers, those that were categorical were quantified as frequency, and the open answers or the interviewer observations were also considered in the analysis, to build up the last version of the intervention.

The OPALS Feasibility Study (Chapter VI) results were analysed descriptively, considering the Activity Diary data, but mostly the Feasibility Questionnaire, which was designed to assess the feasibility of the intervention. The main focus of the analysis was set on quantifying recruitment rate, adherence, and compliance, also the analysis of qualitative data obtained by the observations and comments.

To analyse participants' answers in the OPALS Study Questionnaire, women were divided in two groups, those who performed the intervention for 12 weeks or more, and those who performed the intervention between six and 11 weeks, and the results are shown separately.

Additionally, including those women who did not complete at least six weeks of the intervention, the reasons not to do it are also described.

Chapter IV. Activity behaviour in lean and morbidly obese pregnant women

Chapter IV. Activity behaviour in lean and morbidly obese pregnant women

4.1. Introduction

In the systematic review that was conducted in Chapter II to explore sedentary behaviour during pregnancy, the available literature indicated that pregnant women spend at least half of their waking time sedentary. However, none of the studies gave any detail as to whether sedentary activity levels were different in women of differing obesity levels. This lack of knowledge set the scene for the work in this thesis Chapter which aimed to investigate whether there are differences in total energy expenditure and sedentary time between lean and morbidly obese pregnant women.

In this chapter a cross-sectional study was conducted, assessing energy expenditure, and energy expended in sedentary behaviour among lean and morbidly obese pregnant women, to identify whether there were any differences in how lean and morbidly obese pregnant women behave, in terms of activity including sedentariness. An objective appraisal method, the Actical accelerometer, and a non-objective instrument, the PPAQ (Chasan-Taber L et al., 2004) were used to assess energy expenditure.

It was hypothesised that morbidly obese pregnant women expend more energy in sedentary behaviour than lean pregnant women, as they are supposedly less active.

4.2. Activity behaviour in lean and morbidly obese pregnant women.

The present study was accepted and published in the Scandinavian Journal of Medicine & Sciences in Sports. Fazzi C, Mohd-Shukri N, Denison FC, Saunders DH, Norman JE, Reynolds RM. Activity behaviors in lean and morbidly obese pregnant women. Scand J Med Sci Sports. 2018 May 17. doi: 10.1111/sms.13219.

Authors' contributions

Caterina Fazzi conducted the calculations and the analyses, and wrote the manuscript.

Nor Azwani Mohd Shukri recruited participants, administered the Pregnancy Physical Activity Questionnaires, handed and gave the instructions regarding the Actical accelerometers to the participants, and retrieved the accelerometers data.

David Saunders supervised the conduct of the study and wrote the manuscript.

Jane Norman supervised the conduct of the study and approved the manuscript.

Rebecca Reynolds carried out the study and wrote the manuscript.

The accepted version of the published manuscript is included as follows. The publication is attached as **Appendix 6**.

4.3. Manuscript

Title: Activity Behaviors in Lean and Morbidly Obese Pregnant Women.

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Abstract

Interventions to increase physical activity in pregnancy are challenging for morbidly obese women. Targeting sedentary behaviours may be a suitable alternative to increase energy expenditure. We aimed to determine total energy expenditure, and energy expended in sedentary activities in morbidly obese and lean pregnant women.

We administered the Pregnancy Physical Activity Questionnaire PPAQ (non-objective) and the Actical accelerometer (objective) to morbidly obese (BMI≥40kg/m^2) and lean (BMI≤25Kg/M^2) pregnant women recruited in early (<24 weeks), and late (≥24 weeks) gestation. Data are mean (SD).

Morbidly obese pregnant women reported expending significantly more energy per day in early (n=140 vs 109; 3198.4 (1847.1) vs 1972.3 (10284.8) Kcal/day, $p<0.0001$) and late (n=104 vs 64; 3078.2 (1356.5) vs 1947.5 (652.0) Kcal/day, $p<0.0001$) pregnancy, and expended significantly more energy in sedentary activities, in early (816.1 (423.5) vs 540.1 (244.9) Kcal/day, $p<0.0001$) and late (881.6 (455.4) vs 581.1 (248.5) Kcal/day, $p<0.0001$) pregnancy, than lean pregnant women. No differences were observed in the proportion of energy expended sedentary between lean and morbidly obese pregnant women.

The greater total energy expenditure in morbidly obese pregnant women was corroborated by Actical accelerometer in early (n=14 per group, obese 1167.7 (313.6) Kcal; lean 781.1 (210.1) Kcal, $p<0.05$), and in late (n=14 per group, obese 1223.6 (351.5) Kcal; lean 893.7 (175.9) Kcal, $p<0.05$) pregnancy.

In conclusion, non-objective and objective measures showed morbidly obese pregnant women expended more energy per day than lean pregnant. Further studies are needed to determine whether sedentary behaviours are a suitable target for intervention in morbidly obese pregnancy.

Key words: energy expenditure, lean, morbidly obese, pregnancy.

Background

Among women of reproductive age, obesity (body mass index BMI ≥30kg/m^2) levels have increased in the last decades (1-4). Recent estimates indicate 22% of pregnant women are obese (5), whilst around 2% are severely obese (BMI ≥40kg/m^2) (6).

Obesity in pregnancy is associated with adverse outcomes for mother and offspring (7, 8). Interventions to increase energy expenditure are an option to control weight and gestational weight gain, but these are challenging to implement in morbidly obese pregnant women (9). Indeed previous studies have shown that levels of physical activity are very low among pregnant women (10), particularly amongst those that are overweight/obese compared with normal-weight (11). Overweight individuals expend considerably more calories than normal weight individuals doing the same exercise (12). Obese pregnant women need more energy to move and have a higher metabolic cost than lean pregnant women, so the work of breathing and moving takes a greater effort, and peripheral motor efficiency is decreased (13). Studies comparing physical activity between obese and normal weight pregnant women are very scarce (11), and the majority of interventions based on increasing physical activity levels in obese pregnant women have been largely unsuccessful in preventing adverse pregnancy outcomes (14-16). Targeting a reduction in sedentary behaviours (i.e., activities that expend very low energy, such as sitting or lying or reclining), may be a realistic alternative (17).

Epidemiological studies show that in the general adult population around 55% to 60% of time awake, is spent sedentary (18, 19). In a systematic review, we showed that pregnant women spend more than 50% of their time sedentary (20). A handful of studies suggest increased time in sedentary behaviours during pregnancy is associated with adverse maternal and offspring outcomes. These include higher maternal levels of LDL cholesterol (21), C-reactive protein (21) and gestational diabetes (22), for the mother, and higher new born abdominal circumference (23), and risk of macrosomia (birthweight>4000g) (24), for the offspring.

As little is known about sedentary behaviours in morbidly obese pregnant women, we aimed to determine total energy expenditure, and energy expended in sedentary activities in morbidly obese and lean pregnant women using two validated methods, objective (Actical accelerometer) and non-objective (PPAQ). We hypothesised that morbidly obese pregnant women would expend less energy in total activities, but proportionally more time in sedentary activities than lean pregnant women.

Methods

Subjects were morbidly obese (BMI≥40kg/m^2) women with a singleton pregnancy attending the Antenatal Metabolic Clinic at the Royal Infirmary of Edinburgh, UK, and lean (BMI ≤25 kg/m^2) pregnant women recruited from community antenatal clinics who were participating in a larger study examining the consequences of morbidly obese pregnancy. Details of the overall cohort have been previously described (25, 26).

Ethical approval was obtained from the Lothian NHS Research Ethics Committee, and all subjects gave informed written consent (REC reference number 08/S1101/39).

In this cross-sectional study women were asked to complete the Pregnancy Physical Activity Questionnaire (PPAQ) in early (<24 weeks' gestation), and late (>24 weeks' gestation) pregnancy. The PPAQ is designed specifically for pregnant women to assess the energy expended in activities of different intensities. It contains 36 questions and was validated against the Actigraph accelerometer (Manufacturing Technology, Inc.) in pregnant women in 2004 (27). Results on energy expenditure are given in metabolic equivalents (28) per day and as total activity plus four different activity levels (sedentary, light, moderate and vigorous). Additionally, energy expenditure is given separately in three type of activities (house activities including caring, occupational, and sports or exercise). To show the data in Kcal per day, we calculated the resting metabolic rate (RMR) using the Mifflin and St. Jeor equation (29), which has been tested as the best equation to estimate resting energy expenditure in obese and non-obese adults (30, 31).

Energy expenditure was also assessed in early and late pregnancy, in a subset of women (n=14 per group) using the *Actical* accelerometer (Mini Mitter Company, Inc., US), which gives data on Active Energy Expenditure in kilocalories per minute a day, and has been validated for use in healthy adult populations (32). Sedentary activity was classified as time spent performing activities that register less than 100 counts per minute (33). Women wore the device on their non-dominant wrist, for two weekdays and one weekend day, for 24 hours each day (including sleeping time), and were told to remove the Actical only for bathing, or during water sports activities.

Statistical analyses

Data distribution was tested using the Shapiro-Wilk normality test. Continuous variables including time spent in sedentary behaviours, and relative total daily energy expenditure, were compared between morbidly obese and lean pregnant women using T-tests or ANOVA for normally distributed variables and Mann-Whitney U test for data that were not normally distributed. We compared the proportions of energy expended in the different daily activities between groups using ANOVA or Mann-Whitney as appropriate. Regression analyses were used to adjust for potential confounders when analysing the PPAQ. In particular we adjusted for parity and socio-economic status as these have been reported to influence activity levels in other studies (34) and also differed in our sample (supplementary tables 2 and 3). Differences were accepted as significant at $p < 0.05$. Data were analysed using IBM SPSS Statistics 19.0 software.

Results

The PPAQ was completed by 109 lean and 140 morbidly obese women in early pregnancy (<24 weeks, range 12-23 weeks), and 64 lean and 104 morbidly obese women in late pregnancy (≥24 weeks, range 24-36 weeks).

Table 1 shows the characteristics of participants who completed the PPAQ. Morbidly obese pregnant women had higher BMI, parity, were of lower deprivation category status, were younger, delivered earlier, and gained significantly less weight than lean pregnant women.

Demographics of the women (n=14 lean early; 14 lean late; n=14 morbidly obese early; 14 morbidly obese late) who wore the accelerometer were similar to the full cohort (Supplementary Table 1).

Total Energy Expenditure and Sedentary Energy Expenditure in morbidly obese and lean pregnant women

When comparing reported energy expenditure using the PPAQ between morbidly obese and lean pregnant women, morbidly obese expended significantly more energy per day as total expenditure and in sedentary activities in both early and late pregnancy, as shown in Table 2. These differences remained significant in regression analyses adjusting for maternal age, parity, deprivation status and ethnicity.

Objective measurements of energy expenditure using the Actical confirmed that morbidly obese pregnant women expended significantly more energy than lean pregnant women in early and late pregnancy despite the observation that in both stages of pregnancy morbidly obese pregnant women performed significantly fewer activity counts than lean pregnant women (Table 3).

Proportions of Total Energy Expenditure in different intensity activities

Proportions of energy expended in different intensities of activity are shown in Figure 1 (35). In early and late pregnancy, morbidly obese pregnant women expended significantly more energy in light intensity and significantly less energy in vigorous intensity activities than lean pregnant women. Differences in the proportion of time spent in vigorous activities remained significant after the regression analysis, controlling for maternal age, parity, deprivation status, and ethnicity. Differences in the proportion of time in light intensity activities did not remain significant in adjusted analyses. No differences were observed between lean and morbidly obese pregnant women in the proportion of time spent in moderate or sedentary intensity activities.

Discussion

Our findings demonstrate that morbidly obese pregnant women expend more energy in all physical activities intensities than lean pregnant women. This is despite the observation that morbidly obese pregnant women have fewer objectively measured activity ‘counts’ than lean pregnant women. Further, though both groups spent a similar time in sedentary activities, morbidly obese pregnant women expended more energy when sedentary than lean pregnant women.

Our observation that morbidly obese pregnant women expended significantly less energy in vigorous activities than lean pregnant women corresponds to other studies showing that this domain of physical activity volume is lower among pregnant women (10), but even lower among overweight or obese pregnant women (11). However, we had anticipated that morbidly obese women would spend proportionally more time in sedentary activities than lean women, but objective measures showed time spent sedentary was similar in both groups. The obese group also expended significantly more total energy daily than lean pregnant women in sedentary activities, consistent with their greater basal metabolic rate (30). Though morbidly obese pregnant women expended significantly more total energy than lean pregnant women, they registered significantly fewer activity counts than lean women using the Actical accelerometer. Counts assessed by Actical are an indication of movement in relation to different planes, gravitational forces, magnitude and duration of the sensed acceleration, but not linked to personal characteristics such as gender, age, or body weight (33). Thus interventions designed to increase overall movement, many of which could be performed whilst sedentary i.e. sitting, lying, or reclining, may still be a suitable target for morbidly obese pregnant women. Our observations were similar in early and late pregnancy suggesting any intervention should be started in early pregnancy.

A strength of the study is that we used two different methods to assess energy expenditure and sedentary behaviours, including the PPAQ questionnaire, which has been validated in pregnancy, and an objective device. Due to the detailed characterisation of the women we were able to adjust for potential confounding factors including parity and socioeconomic status which were associated with differences in energy expenditure in our sample, as has been reported by others (34). Findings remained significant after adjustment for these confounders. Limitations include the risk of recall bias and potential for lack of reliability of the PPAQ, since subjects might be dishonest or inaccurate in their responses. We also acknowledge the small sample size used with the Actical accelerometer limits interpretation of results. Whilst subjects wore the accelerometer for the recommended time of the manufacturer, we acknowledge this was for a relatively short time. Despite this, the Actical findings for energy expenditure were consistent with the PPAQ outcomes. A further strength is the focus on morbidly obese pregnant women, who may be unable to participate in interventions designed for less severely obese women (15, 36), and have also been identified to have specific barriers to participation in physical activity interventions (37). We acknowledge that time spent sleeping, which may impact on the time spent sedentary, was not specifically assessed in our study, but we are not aware that sleep duration differs between morbidly obese and lean pregnant women (38).

Though we used two validated measures to assess physical activity in pregnancy, neither was specifically designed to understand sedentary activities in pregnancy. A recent systematic review highlighted the heterogeneity in assessment of sedentary activity (20) with measures ranging from seven to 18 hours per day.

Perspective

A better understanding of sedentary activity is needed for the design of effective interventions to help to reduce the adverse effects of obesity on pregnancy, especially as obesity prevalence is growing among fertile women (39), and that there are risks associated with obesity during pregnancy, for mothers and offspring. We have shown that morbidly obese pregnant women expend significantly more energy than lean pregnant women, but they also expend significantly more energy on sedentary activities. These findings suggest that energy expenditure might not be the key factor to obesity, but energy intake might be. Nevertheless, sports and physical activity interventions may play a role as preventive health factors contributing to better and effective alternatives to reduce those risks associated with obesity during pregnancy, and to reduce time spent sedentary.

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Tables.

Table 1. Characteristics of obese and lean participants who completed the PPAQ in early and late pregnancy.

Characteristic	EARLY			LATE		
	Lean (n=109) Mean (SD) or n (%)	**M. Obese** (n=140) Mean (SD) or n (%)	*p*-value	**Lean** (n=64) Mean (SD) or n (%)	**M. Obese** (n=104) Mean (SD) or n (%)	*p*-value
BMI (Kg/m²)	22.8 (2.7)	44.2 (4.5)	p=0.000	22.8 (1.6)	44.1 (5.0)	p=0.000
Maternal age (years)	33.06 (4.55)	30.73 (5.40)	p=0.000	33.61 (4.45)	31.50 (5.26)	p=0.010
Parity			p=0.003			p=0.003
0	68 (62.4)	64 (46)		41 (64.1)	43 (41)	
1	29 (26.6)	41 (29.5)		16 (25)	38 (36.2)	
2	12 (11)	31 (41)		7 (10.9)	20 (19)	
3	0 (0)	2 (1.4)		0 (0)	2 (1.9)	
4	0 (0)	0 (0)		0 (0)	0 (0)	
5	0 (0)	0 (0)		0 (0)	2 (1.9)	
Ethnicity			p=0.081			p=0.169
Caucasian	97 (89)	124 (89.2)		54 (84.4)	84 (81)	
Other	0 (0)	4 (2.9)		0 (0)	3 (2.9)	
Deprivation Category			p=0.000			p=0.000
Low	28 (25.9)	11 (8.0)		15 (24.6)	12 (11.7)	
Middle	79 (73.1)	103 (75.7)		46 (75.4)	79 (76.7)	
High	1 (0.9)	22 (16.2)		34 (0)	12 (11.7)	
Birth weight (g)	3513 (541)	3574 (558)	p=0.251	3584 (512)	3511(595)	p=0.540
Gestational age at delivery (week)	40.34 (1.34)	39.79 (1.50)	p=0.003	40.50 (1.38)	39.68 (1.42)	p=0.001
Weight gain (kg)	10.16 (3.64)	5.87 (5.03)	p=0.000	10.41 (4.05)	5.59 (5.53)	p=0.000

Data are mean (SD) or n (%). Weight gain was calculated as Weight week 36 –weight weight at baseline. Deprivation Category is based on postcodes.

Table 2. PPAQ comparisons in total and sedentary energy expenditure between lean and morbidly obese pregnant women in early and late stage.

	Early Mean (SD)			**Late** Mean (SD)		
	Mean (SD)		**β (95% CI) †**	Mean (SD)		**β (95% CI) †**
	Lean (n=109)	M.Obese (n=140)		Lean (n=64)	M.Obese (n=104)	
Total EE (Kcal/day)	1972.29 (1028.85)	3198.37 (1847.05)	0.33**(575.73-1390.80)	1947.54 (652.03)	3078.23 (1356.46)	0.43**(699.87-1631.39)
Sedentary Activity EE (Kcal/day)	590.13 (244.90)	816.07 (423.51)	0.37**(180.08-397.11)	581.11 (248.51)	881.65 (455.38)	0.34**(110.69-360.39)

β is the standardised coefficient; **Significant at $p<0.001$; †Adjusted for Maternal Age, Parity, Deprivation Category, and Ethnicity.

Table 3. Actical comparisons in counts, total energy expenditure, and sedentary time between lean and morbidly obese pregnant women in early and late stage.

	Early Mean (SD)			**Late** Mean (SD)		
	Lean (n=14)	M.Obese (n=14)	**Sig**	Lean (n=14)	M.Obese (n=14)	**Sig**
Sedentary time (min/day)	762.40 (104.68)	799.33 (101.80)	p=0.353	740.70 (89.89)	774.15 (124.70)	p=0.423
Total Activity Counts* (per day)	360160.91 (131302.13)	268683.36 (83567.16	p=0.037	357561.03 (94799.09)	266820.25 (97640.51)	p=0.004
Total EE (Kcal/day)	781.06 (210.15)	1167.69 (313.56)	p=0.001	893.72 (175.88)	1223.64 (351.47)	p=0.019

*Counts are markers of movement.

Supplementary Tables.

Supplementary Table 1. Characteristics of Actical accelerometer participants by groups.

Characteristic	Lean Early* (n=14) Mean (SD)	M. Obese Early* (n=14) Mean (SD)	*p*-value	Lean Late† (n=14) Mean (SD)	M. Obese Late† (n=14) Mean (SD)	*p*-value
Maternal Age (years)	31.08 (4.96)	31.43 (5.11)	p=0.859	34.62 (4.81)	34.86 (4.19)	p=0.889
BMI (Kg/m^2)	23.44 (1.18)	43.65 (2.99)	p=0.000	25.81 (2.13)	44.00 (2.69)	p=0.000
% Fat mass	30.08 (3.76)	49.26 (1.58)	p=0.000	33.09 (3.24)	50.36 (2.23)	p=0.000
Parity			p=0.246			p=0.329
0	9 (64.3)	6 (42.9)		7 (50)	6 (42.9)	
1	4 (28.6)	4 (28.6)		6 (42.9)	3 (21.4)	
2	0 (0)	3 (21.4)		1 (7.0)	2 (14.3)	
3	1 (7.1)	0 (0)		0 (0)	1 (7.1)	
4	0 (0)	1 (7.1)		0 (0)	1 (7.1)	
5	0 (0)	0 (0)		0 (0)	1 (7.1)	
Ethnicity			p=0.541			p=0.541
1 (Caucasian)	14 (100)	12 (85.71)		14 (100)	12 (85.71)	
2 (40)	0 (0)	2 (14.29)		0 (0)	2 (14.29)	
Deprivation Category			p=0.001			p=0.000
Low	7 (50)	1 (7.15)		4 (28.6)	0 (0)	
Middle	7 (50)	12 (85.7)		10 (71.4)	11 (78.6)	
High	0 (0)	1 (7.15)		0 (0)	3 (21.4)	
Birthweight (gr)	3844.73 (463.88)	3581.75 (763.34)	p=0.333	3910.00 (485.02)	3819.50 (421.38)	p=0.639
Weight Gain (Kg)	10.39 (4.92)	5.49 (1.91)	p=0.058	12.19 (3.82)	7.44 (6.05)	p=0.031
BMR (Kcal/day)	1442.79 (75.20)	1894.21 (97.08)	p=0.000	1496.71 (86.79)	1929.57 (106.06)	p=0.000

*Early gestation is between 14 and 23 weeks (median 17.93 weeks).
†Late gestation is between 27 and 37 weeks (median 29.36).

Supplementary Table 2. Comparisons on energy expenditure between nulliparous and multiparous pregnant women.

	Early Mean (SD)			**Late** Mean (SD)		
	Nulliparous (n=132)	**Multiparous** (n=117)	***p*-value**	**Nulliparous** (n=84)	**Multiparous** (n=84)	***p*-value**
Total EE (Kcal/day)	2178.16 (1133.9)	3207.14 (1962.1)	p=0.000	2367.70 (1218.1)	2927.29 (1254.6)	p=0.000
Sed EE (Kcal/day)	762.14 (335.7)	666.43 (406.9)	p=0.008	811.03 (474.6)	723.28 (343.7)	p=0.256
Light EE (Kcal/day)	688.46 (461.4)	1274.69 (654.0)	p=0.000	754.42 (481.8)	1225.42 (561.6)	p=0.000
Mod EE (Kcal/day)	695.76 (791.4)	1236.79 (1351.4)	p=0.000	780.77 (864.2)	956.04 (810.7)	p=0.008
Vig EE (Kcal/day)	30.58 (59.4)	29.34 (67.6)	p=0.352	21.62 (49.0)	21.94 (54.4)	p=0.712

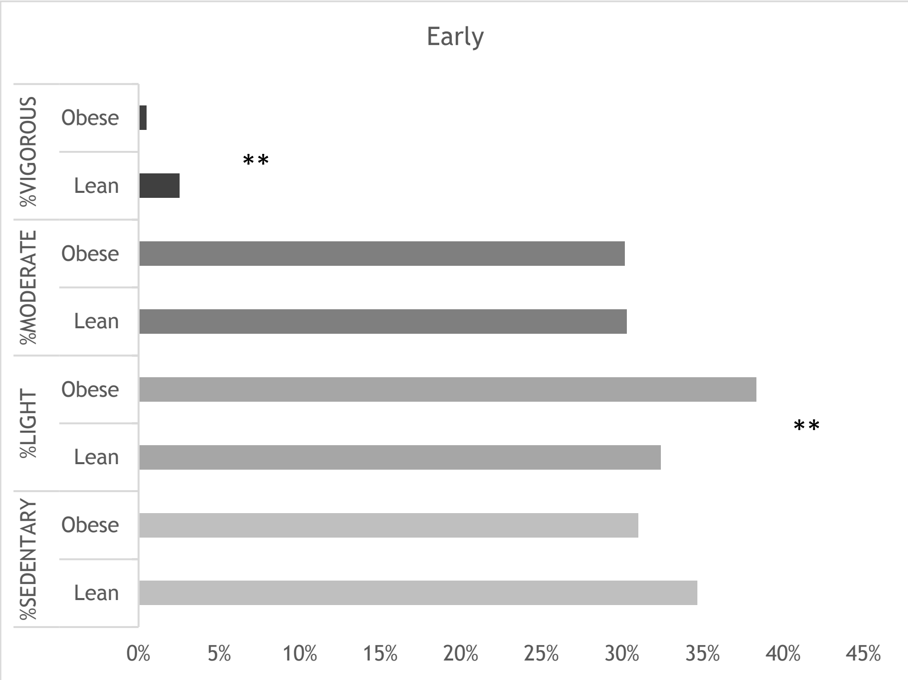
Supplementary Table 3. Comparisons on energy expenditure between most deprived and least deprived pregnant women.

	Early Mean (SD)			**Late** Mean (SD)		
	Most Deprived (n=167)	**Least Deprived** (n=78)	***p*-value**	**Most Deprived** (n=110)	**Least Deprived** (n=53)	***p*-value**
Total EE (Kcal/day)	2531.19 (1608.6)	2844.74 (1598.0)	p=0.03	2588.14 (1335.9)	2816.03 (1133.9)	p=0.102
Sed EE (Kcal/day)	733.44 (367.9)	689.58 (387.1)	p=0.224	769.92 (452.7)	756.66 (336.6)	p=0.992
Light EE (Kcal/day)	878.67 (604.6)	1131.62 (654.5)	p=0.003	942.24 (572.4)	1106.75 (569.2)	p=0.063
Mod EE (Kcal/day)	892.70 (1065.1)	986.13 (1047.2)	p=0.220	853.58 (925.4)	932.70 (668.7)	p=0.097
Vig EE (Kcal/day)	25.45 (47.3)	37.50 (87.2)	p=0.948	22.24 (51.8)	19.49 (49.9)	p=0.461

Figures

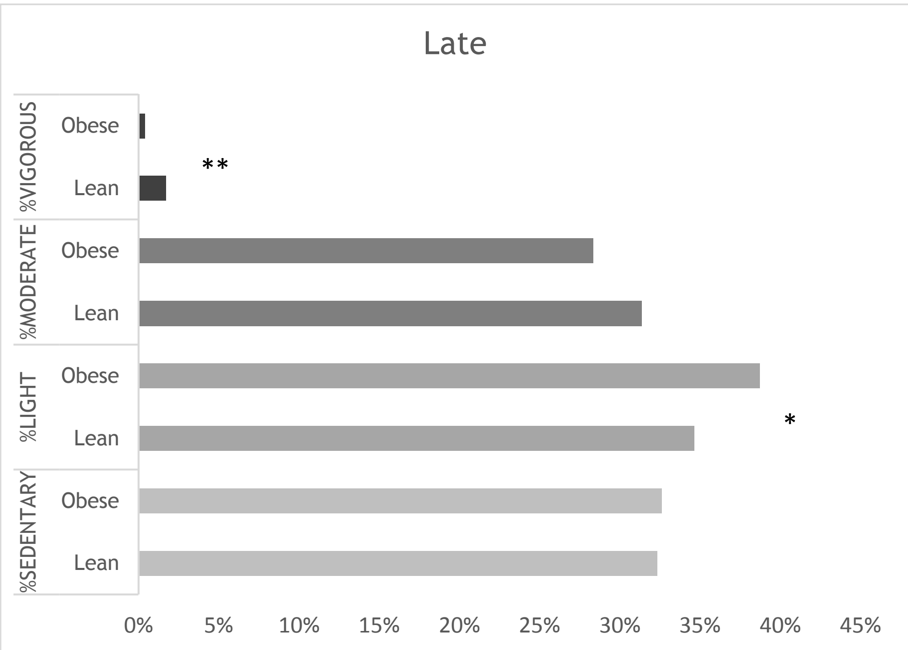
Figure 1.

a) Percentage of self-reported Energy Expenditure per Activity Intensity in early pregnancy.



*Significant at p<0.05; **Significant at p<0.001

b) Percentage of self-reported Energy Expenditure per Activity Intensity in late pregnancy.



*Significant at p<0.05; **Significant at p<0.001

4.4. Conclusion

A cross-sectional study was conducted including lean and morbidly obese pregnant women in early (<24 weeks), and late (≥24 weeks) pregnancy. Using the PPAQ, and the Actical accelerometer, pregnant women were assessed to estimate total energy expenditure and energy expended in sedentary behaviour. Also, energy expended in light, moderate and vigorous activities was assessed using the PPAQ, and time spent sedentary using the Actical.

Morbidly obese pregnant women expended significantly more energy than lean pregnant women in total, based on the PPAQ and the Actical. Similarly, in sedentary activities morbidly obese pregnant women also expended significantly more energy based on the PPAQ. Otherwise, when looking at the proportion of energy expended in different activities using the PPAQ, no differences were observed between lean and morbidly obese pregnant women in sedentary and moderate activities, but differences were observed for vigorous (significantly higher among lean pregnant women), and light activities (significantly higher among morbidly obese pregnant women). Similarly, according to the accelerometer, no differences were found between morbidly obese pregnant women and lean pregnant women in time spent sedentary.

To explain the findings, no differences were observed in terms of the time spent in sedentary behaviour between lean and morbidly obese pregnant women. However, energy expended in sedentary activities was significantly higher among the morbidly obese, which is unexpected and difficult to explain. Nonetheless, the explanation apparently lies in the effect of weight. This means that, to perform any activity, morbidly obese pregnant women expend much more energy compared to lean pregnant women, even when they perform the same movement. Therefore, morbidly obese pregnant women spent the same time on sedentary activities, but expending significantly more energy because of their weight.

In terms of the proportions of energy expended in sedentary activities, contrary to what was hypothesised, this chapter has shown that lean and morbidly obese pregnant women behave similarly. This might be explained by the significant differences in the relative proportions of energy expended in light-intensity activities and vigorous-intensity activities between the two groups. Morbidly obese pregnant women expended proportionally more energy in light-intensity activities, and less in vigorous-intensity activities, whilst lean pregnant women expended proportionally more in vigorous-intensity activities and less in light-intensity activities. Consequently, as both groups expended similar proportions in sedentary activities and in moderate-intensity activities, all is balanced out. However, this does not address why morbidly obese pregnant women expended significantly more energy in sedentary activities compared with the lean pregnant women, since there were no proportional differences between the groups. This can be potentially explained by the significant differences that were observed in the total energy expenditure, where morbidly obese pregnant women expended significantly more than the lean. When comparing the amount of energy expended in sedentary behaviour by the morbidly obese and lean pregnant women, morbidly obese expended significantly more energy than lean despite the proportions being similar.

It has also been observed that morbidly obese pregnant women registered significantly less counts per minute than lean pregnant women, which means that the number and/or magnitude of movements were significantly less among morbidly obese participants. On the contrary, morbidly obese pregnant women expended significantly more energy per day than lean pregnant women. This might be due to the substantial effect that weight has on the energy expended on each movement. Consequently, even when morbidly obese pregnant women moved less than lean pregnant women, since they expended much more energy in each movement, the total energy expenditure was significantly higher than the energy expended by the lean pregnant women who moved significantly more.

There are different examples of interventions with obese non-pregnant people to reduce risks associated with obesity. A systematic review and meta-analysis reported that interventions involving diet advice, involving or not exercise, may decrease premature all-cause mortality in obese adults (34 trials, 685 events; RR 0.82; 95% CI 0.71-0.95). The review included 54 randomised controlled trials with 30,206 obese adults. Of the 54 trials three (5%) did not involve physical activity in the intervention, 22 (40.7%) involved an exercise programme, and 29 trials (53.7%) provided advice to increase exercise, but not an exercise programme (Chenhan M et al., 2017).

Strategies aiming to modify sedentary behaviour among obese people have also shown favourable outcomes for health. One study involved 19 obese adults to test three different strategies to regularly break up prolonged sitting, with walking at different intensities. Authors observed that when prolonged sitting is interrupted regularly with breaks involving light and moderate-intensity activities, systolic (p=0.002) and diastolic (p=0.03) blood pressure levels were significantly lower, even after adjusting for potential confounders (Larsen RN et al., 2014).

These examples support the idea that specific interventions for morbidly obese pregnant women might help them to reduce the risks that obesity means for pregnancy outcomes, as this approach has worked with obese adult subjects in the general population. In the next chapter the plan was to design a physical activity intervention involving morbidly obese pregnant women, based on active sitting exercises, to be performed mainly in place of the time they usually spend sedentary.

Chapter V. Design of an active sitting intervention, to reduce sedentary behaviour in morbidly obese pregnant women, using patient involvement in developing the research strategy

Chapter V. Design of an active sitting intervention, to reduce sedentary behaviour in morbidly obese pregnant women, using patient involvement in developing the research strategy

5.1. Introduction

In Chapter IV it was highlighted that morbidly obese pregnant women expend significantly more energy in general activities, than lean pregnant women, but they also expend significantly more energy in sedentary behaviour than lean pregnant women. This suggests that there may be a need for interventions specifically designed for morbidly obese pregnant women, aiming to change the time they spend sedentary with activities of more intensity with an ultimate aim of helping to improve pregnancy outcomes for them and their babies by decreasing the risks associated with too much time sedentary. In this chapter the aim is to address this by including pregnant women in the design of an exercise intervention for morbidly obese pregnant women, which can be performed during their pregnancy.

5.1.1. Interventions with obese pregnant women.

Studies have observed that obese women have low adherence to exercising during pregnancy (Nascimento S et al., 2011). However, there is some evidence that home-based physical activity interventions are associated with increasing compliance, as apparently exercising in a familiar and comfortable setting seems to be of particular interest for obese pregnant women (Ong MJ et al., 2009).

In general, modest attention has been set on light-intensity activity and sedentary behaviour during pregnancy (Di Fabio DR et al., 2015), though promoting pregnant women to spend more time in light-intensity activities, would directly reduce the time they spend sedentary, encouraging maternal and child health benefits (da Silva SG et al., 2017).

5.1.2. Involving participants in the study design.

Aiming to design and develop effective interventions to reduce sedentary behaviour and increase energy expenditure, a literature search was performed to learn from others experiences involving participants in the intervention design process. Involving participants in the development and evaluation of interventions might be helpful to answer difficult uncertainties, as we can get feedback right from the protagonists (Smith SM et al., 2013).

No studies designing physical activity or exercise interventions involving pregnant participants were found in the literature, and only a few studies have been published involving participants and public in the intervention design. The following are examples of studies which have involved participants when designing other kinds of interventions:

One study involved patients and family members in the design of an educational strategy aiming to improve breast cancer screening rates among women (Kagawa-Singer M, Tanjasiri SP, Valdez A, Yu H, & Foo MA, 2009; Tanjasiri SP et al., 2007). All (n=434) participants took part in the design of the intervention, but also in the evaluation, interpretation of the results, and reporting the findings. For the design of the intervention, data was mostly collected by focus groups guided by women susceptible to develop breast cancer, as well as through interviews involving the major community leaders. The chosen collaborative approach was crucial to the final success, particularly among ethnically diverse populations, according to the researchers.

In another study the researchers used a community-based participatory research approach, with groups of immigrants who had asthma, and were culturally and linguistically different than the locals, aiming to guarantee the implementation of an effective educational intervention to improve participant's knowledge on asthma, and the management of asthma in their own community (Poureslami I, Nimmon L, Doyle-Waters MMR, & FitzGerald JM, 2011). Researchers wanted the patients' opinions related to making decisions together with the community, in order to create effective educational material, responding to the cultural and linguistical requirements. Researchers chose a focus group method including 29 participants, as they thought it was a practical approach, to first obtain information about participants' values, beliefs and practices related with asthma, so from that baseline they could involve them in the development of the suitable (linguistically and culturally) educational material.

5.1.3. Involving pregnant women in the study design.

The UPBEAT Study is a key example of a trial that incorporated obese pregnant women's views into the study design. Using interviews with obese pregnant women the researchers aimed to determine the feasibility and acceptability of a diet and physical activity intervention, to be used later on in a pilot study (Poston L et al., 2013). The authors did not explicitly mention that they involved patients in designing the exercises included in the physical activity intervention. Rather, they reported that health trainers, who were in charge of administering the physical activity strategy during the randomised controlled trial, were specifically trained to give the proper advice. During the trial, women in the study group attended a personal interview with the health trainer to discuss the potential advantages of exercising, received a handbook, a logbook, a pedometer and a DVD with exercises. They were invited to participate once a week in a session with the health trainer for eight weeks, focused on increasing walking at a moderate intensity, and having a more active lifestyle (Briley AL et al., 2014). Later on, based on the explained intervention design, a randomised controlled trial was conducted with women with obesity, using a behavioural intervention based on physical activity and diet on the study group, including 629 pregnant women, and standard antenatal care in the control group, including 651 pregnant women. Researchers aimed to decrease the incidence of babies large for gestational age, and to prevent GDM. Differences between groups were not observed (Poston L et al., 2015). Considering participants' views into the study design rather than involving the participants in designing the whole intervention might be a weakness of the intervention, and therefore would be a reason why the authors did not accomplish the aims.

5.1.4. Antenatal Metabolic Clinic.

The antenatal metabolic clinic offers specialist antenatal care for pregnant women with BMI≥40 Kg/m^2. At the clinic, women are advised about healthy lifestyles in pregnancy and are reviewed by a specialist dietician for tailored dietary advice. Our previous surveys in the clinic have revealed that women receive little information about physical activity in pregnancy, have less knowledge about the benefits of physical activity in pregnancy, but has also highlighted that there are several barriers to taking up any physical activity for women with BMI≥40 Kg/m^2 (Denison FC et al., 2015; Weir Z et al., 2010).

5.2. Aim

To design a physical activity intervention for severely obese pregnant women based on sitting exercises.

Objectives:

- To learn what obese pregnant women know about sedentary behaviour.
- To learn whether obese pregnant women receive advice on physical activity and sedentary behaviour during pregnancy.
- To understand women's perception of a proposed exercise plan to reduce time spent sedentary, regarding difficulty, comfort, the number of repetitions, and sets, regarding technique, difficulty, intensity, and comfort.
- To design a motivating exercise intervention to reduce time spent sedentary, from the morbidly obese pregnant women's point of view.

A short questionnaire (**Appendix 3**) was administered to morbidly obese pregnant women, looking at the knowledge that participants had about sedentary behaviour, and the risks that sedentary behaviour mean for health, also collected data on the advice that morbidly obese pregnant women receive on physical activity during pregnancy, and participants' interest in modifying their sedentary behaviour. The data obtained through the questionnaires set a baseline of the design to design a suitable exercise intervention to perform while sitting.

Different intervention taxonomies were considered to design the intervention, trying to include all the relevant and indispensable elements that should be comprised in a pertinent and relevant strategy (Schulz R, Czaja SJ, McKay JR, Ory MG, & Belle SH, 2010). Thus, considering the population in the current study, morbidly obese pregnant women, and the outcomes that we were targeting, we decided that involving patients in the design of the exercise intervention, was by far the best way to achieve a feasible and successful intervention. For our study, in particular, we needed the patients to clarify how capable morbidly obese pregnant women were to exercise, considering the significant weight they are constantly carrying, trying to design an intervention that might be effective, and safe, but at the same time interesting, comfortable, challenging, and suitable for their needs.

5.3. Methods

5.3.1. 1st Stage: Sedentary behaviour and physical activity in pregnancy.

5.3.1.1. Aim

To learn what morbidly obese pregnant women know about sedentary behaviour, the advice they are receiving on physical activity and sedentary behaviour during pregnancy, and the motivation they have in exercising during pregnancy while they are sedentary.

5.3.1.2. Data collection

A questionnaire (**Appendix 3**) based on 10 questions was designed, asking about women's knowledge of sedentary behaviour, the recommendations obtained for physical activity and sedentary behaviour during pregnancy, and their interest in learning in how to reduce the time they spend sedentary, and whether they are motivated to exercise while sitting or not. The questionnaire was reviewed and then approved by two of the experts who work in the Antenatal Metabolic Clinic, Dr Fiona Denison and Professor Rebecca Reynolds.

The questionnaire was administered by Tommy's midwives at the Antenatal Metabolic Clinic, and most of the women completed it in the waiting room.

5.3.1.3. Setting

The study was conducted at the Antenatal Metabolic Clinic, Royal Infirmary of Edinburgh, Edinburgh between 23rd August 2016 and 7th March 2017.

5.3.1.4. Sample

Inclusion criteria

- Pregnant women (at any stage of pregnancy).
- Attending the Tommy's Antenatal Metabolic Clinic.
- Body mass index (BMI) 40 Kg/m^2 or over.

5.3.1.5. Data analysis/synthesis

Responses from the questionnaire were collated and a descriptive analysis was conducted to describe the frequency and proportions of each answer.

5.3.2. 2nd Stage: Intervention Design.

5.3.2.1. Aim

To design with morbidly obese pregnant women, an exercise intervention based on exercises to be performed mostly sitting.

5.3.2.2. Data collection

We used a patient involvement in research method to design a realistic, feasible, suitable, interesting, and motivating exercise intervention, specifically designed for pregnant women with morbid obesity.

The midwives at the Antenatal Metabolic Clinic invited the patients meeting the inclusion criteria, to take part in the study, by participating in interviews. The invitation was to take part in the design of an exercise intervention based on activities performed mostly in a sitting position, to reduce the time spent sitting or lying, and increase the energy expenditure. The patients who agreed in taking part had personal interviews with the researcher, where they discussed and tested all the proposed exercises. Women's feedback was recorded on a Feedback Form (**Appendix 4**) specially designed for the study, describing the number of repetitions they felt right, the perception of intensity using the 1-10 Borg's Rating of Perceived Exertion Scale (Borg G, 1998), if comfortable (Yes or No), and comments, on each of the exercises.

5.3.2.3. Setting

The study was conducted at the Antenatal Metabolic Clinic, Royal Infirmary of Edinburgh, Edinburgh between 14th March 2017 and 30th May 2017.

5.3.2.4. Sample

Inclusion criteria

- Pregnant women (at any stage of pregnancy).
- Attending the Tommy's Antenatal Metabolic Clinic.

- Body mass index (BMI) 40 Kg/m^{2}or over.

Exclusion criteria

- Have any contraindication to perform the proposed exercises, according to the consultant.

Sample size

We intended to test the proposed exercise intervention on up to 30 subjects, or until data saturation (i.e. obtaining the same responses by more than five subjects, for all the exercises).

5.3.2.5. Exercise intervention

Based on available literature recommendations (Davenport MH et al., 2008; Mottola MF, 2009, 2016; NICE, 2010), the researcher supported by the supervisors, specially David Saunders who is a Senior Lecturer in Exercise Physiology, designed a series of six low-intensity exercises based on FITT guidelines (Bulger S, 2010), involving most of big muscle groups, to work them alternatively, following the training principles (Kenney WL, Wilmore JH, & DL, 2015), which could be done while sitting, as we tried to offer an active, but similar alternative to sedentary behaviour, which was the target. We proposed a range of repetitions, time, and sets, which should last between 30 to 40 minutes, including pauses, acknowledging what is recommended for obese pregnant women (Mottola MF, 2013). A soft ball was also involved, which was used in four of the six exercises. It was used to be held in two of the exercises, to help participants to make the exercise technically more stable and precise. The ball was also employed in other two exercises to be squeezed, offering resistance and improving the intensity of the exercise, to deliver a better and proper muscular work. The exercise intervention would make participants at least expend more energy, gain muscle mass, and reduce the time sedentary.

Proposed exercises

Figure 5. Exercise 1

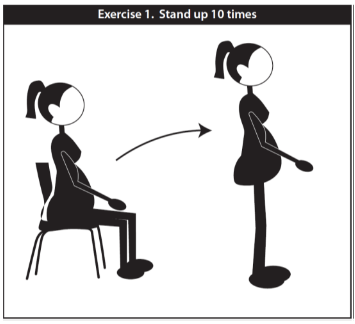


Figure 6. Exercise 2

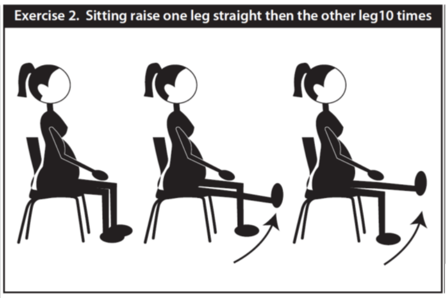


Figure 7. Exercise 3

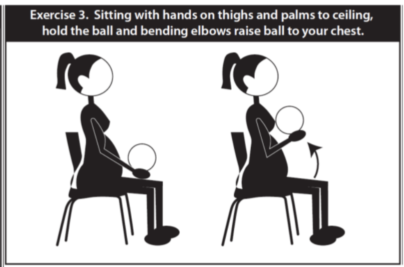


Figure 8. Exercise 4

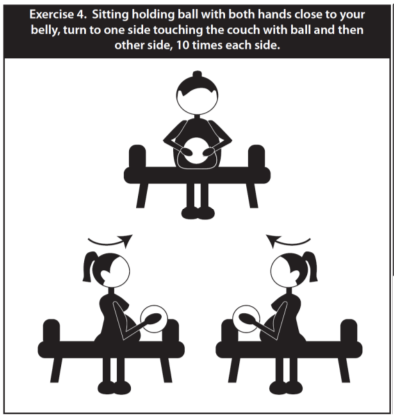


Figure 9. Exercise 5

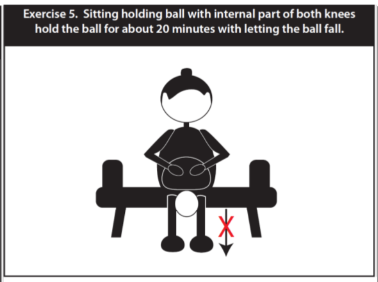
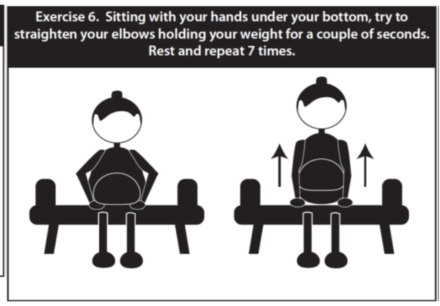


Figure 10. Exercise 6



We invited women to carry out the exercises and sought their feedback to improve these.

Through personalised interviews women learned how to do and tested each exercise, reporting their feelings regarding intensity, using the 1-10 Borg's Rating of Perceived Exertion Scale (Borg G, 1998), comfort, perception on the number of repetitions, or time holding the exercise, and sets. Women were also asked if they had any comments or suggestions to improve the intervention. All answers were collected by the researcher in a specially designed Feedback Form (**Appendix 4**).

5.3.2.6. Materials

To test the intervention each woman used a ball of 21 cm diameter which was provided by the researcher. The ball was used to be squeezed, or held, and used in four of the six exercises included in the final strategy.

5.4. Data analysis/synthesis

We analysed the frequency of the number of repetitions, or the time holding on each exercise, which participants declared to be comfortable and between 4 to 5 on the Borg's Scale. Based on those frequencies, we established the proposal ranges, aiming to offer a challenging and helpful exercise intervention, which might also satisfy all participants' capabilities. We also integrated the feedback from women from their specific comments, in order to improve the overall exercise plan.

Once data saturation had been agreed in the range of numbers (times, repetitions, and sets) for each exercise, the definitive exercise plan was finalised.

5.5. Results

5.5.1. 1st Stage: Questionnaire

43 morbidly obese pregnant women answered the questionnaire. Seventy-four per cent (n=32) had not heard about sedentary behaviour (**Table 8**). Most participants (97.7%; n=42) were interested in doing at least one of the three proposed exercises while sedentary. Sixty point five per cent (n=26) were interested in doing the three

proposed exercises (3/3); 12 (2 were interested in doing two of the three exercises (2/3), four (9.3%) women said they would do one of the three exercise (1/3), and one woman (2.3%) was not interested in doing any of the three exercises (0/3) (**Tables** 8 and **9**).

Table 8. Results Sedentary behaviour and physical activity questionnaire

Questions		Yes	No	Blank
Have you heard about SB?		10 (23%)	32 (74%)	1 (2%)
Are you interested in know about SB?		25 (58%)	14 (33%)	4 (9%)
Would you do exercise	1?	41 (95%)	1 (2.3%)	1 (2.3%)
	2?	35 (81%)	6 (14%)	2 (5%)
	3?	30 (70%)	10 (23%)	3 (7%)

Table 9. Frequency of interest in doing exercise 1, or exercise 2, or exercise 3

Exercises (n=43)	Frequency (%)
All exercises (3/3)	26 (60.5%)
2 exercises (2/3)	12 (27.9%)
1 exercise (1/3)	4 (9.3%)
None (0/3)	1 (2.3%)

5.5.2. 2nd Stage: Intervention Design

A total of 23 women took part in the intervention design.

The first six proposed exercises are explained as follows:

Exercise 1. Stand up and sit 10 to 15 repetitions.

Exercise 2. In sitting position straighten the legs and bend them, 10 repetitions.

Exercise 3. In sitting position hold the ball with the hands and bend the elbows 20 repetitions.

Exercise 4. In sitting position hold the ball with the hands and turn to the right, back to the centre and then turn to the left to return to the centre, repeat 20 times.

Exercise 5. In sitting position, put the ball between your knees, and hold it for ten seconds.

Exercise 6. In sitting position, put your hands under your thighs, and try to straighten the elbows feeling your weight on your arms for five seconds.

After testing those exercises and obtaining similar feedback from the first six participants, and following the women's observations we realised that most exercises were perceived as too easy: one woman declared "*the intervention is not interesting if there is no challenge*". Therefore, following the feedback we changed five of the exercises, adding some difficulty, e.g. adding props, including additional leg exercises or asking women to do the exercises with the arms in extension rather than bent.

We then tried the six modified exercises with other participants, which are shown below:

Exercise 1. From sitting stand up, and before sitting back squat.

Exercise 2. In sitting position, straight both legs, and hold the ball with your feet.

Exercise 3. In sitting, with your elbows bent and both forearms in a horizontal position, hold and squeeze the ball, then release without moving the arms, and squeeze again.

Exercise 4. In sitting position, hold the ball with both hands with your elbows in extension, turn to one side then to the other side.

Exercise 5. In sitting position hold the ball with the internal part of both knees, squeeze, then release and do it again.

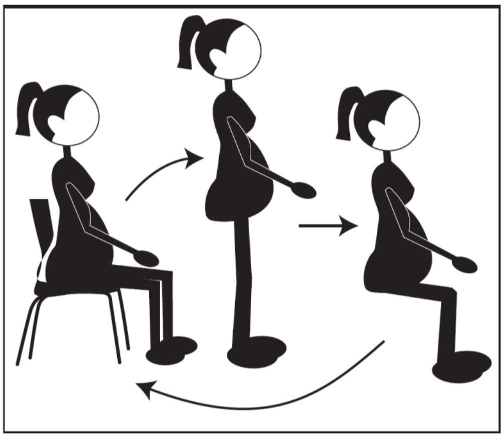
Exercise 6. In sitting position, put your hands under your thighs, and try to straighten the elbows feeling your weight on your arms, release and repeat.

However, we wanted not only to test the exercises, but also to decide the number of repetitions, or time to hold, and the number of sets.

17 more obese pregnant women took part in testing the new exercise strategy, and with their feedback we completed the last version of the exercise intervention. As we got the same feedback with the last nine participants, we stopped recruitment. In the final protocol six exercises were included, to be done in two sets of 10 repetitions:

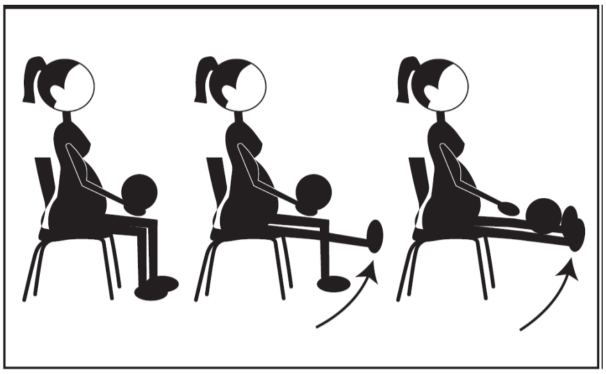
Exercise 1. From sitting, take yourself to a standing position. Before sitting back down, squat for five seconds. Repeat 10 times. Two sets.

Figure 11. Exercise 1



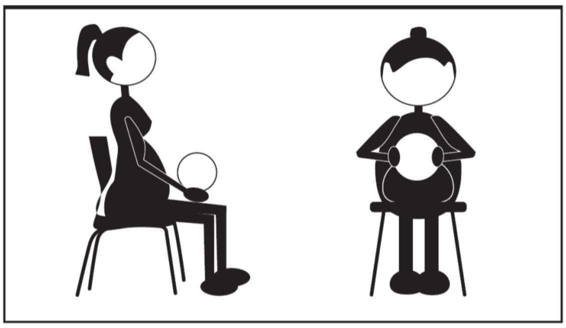
Exercise 2. In sitting position, straighten both legs, and hold the ball with your feet holding still for 20 seconds. Repeat 10 times. Two sets.

Figure 12. Exercise 2



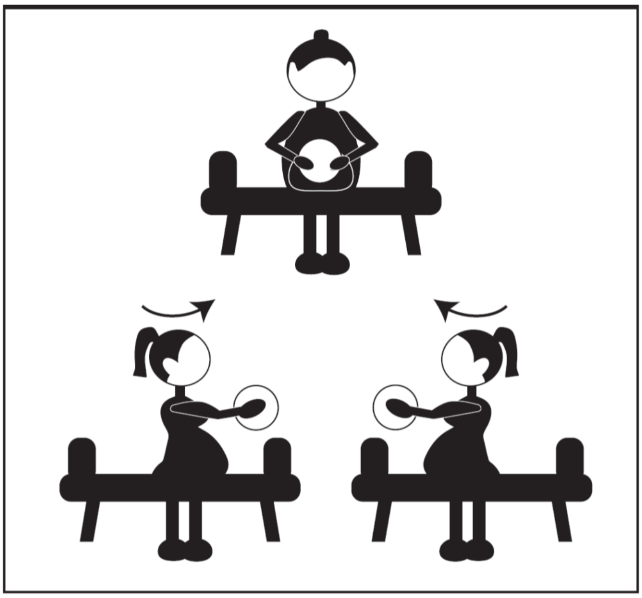
Exercise 3. In a sitting position, with your elbows bent and both forearms in a horizontal position, hold and squeeze the ball for 10-15 seconds, then release without moving the arms, and squeeze again. Repeat 10 times. Two sets.

Figure 13. Exercise 3



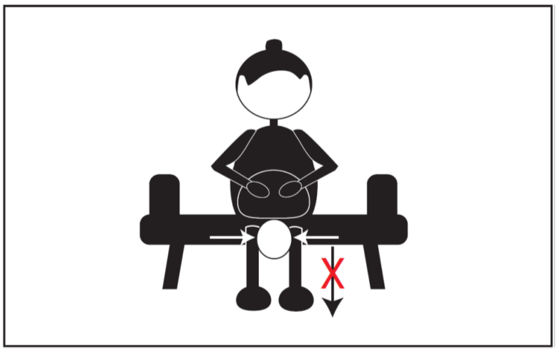
Exercise 4. In sitting position, hold the ball with both hands with your elbows in extension. Turn to one side then to the other side. Repeat 10 times (both sides is one repetition). Two sets.

Figure 14. Exercise 4



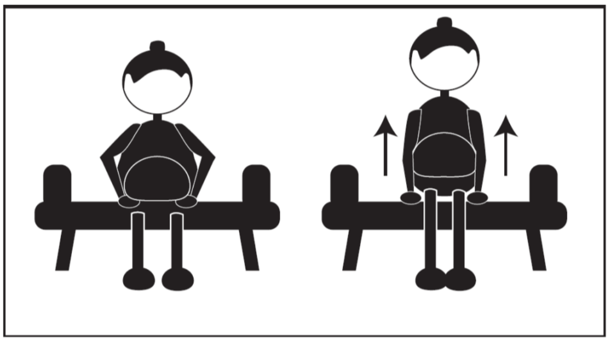
Exercise 5. In sitting position hold the ball with the internal part of both knees, squeeze for 10-15 seconds, release and do it again. Repeat 10 times. Two sets.

Figure 15. Exercise 5



Exercise 6. In sitting position, put your hands under your thighs, and try to straighten the arms feeling your body weight for 10-20 seconds, release and repeat 10 times.Two sets.

Figure 16. Exercise 6



5.6. Discussion

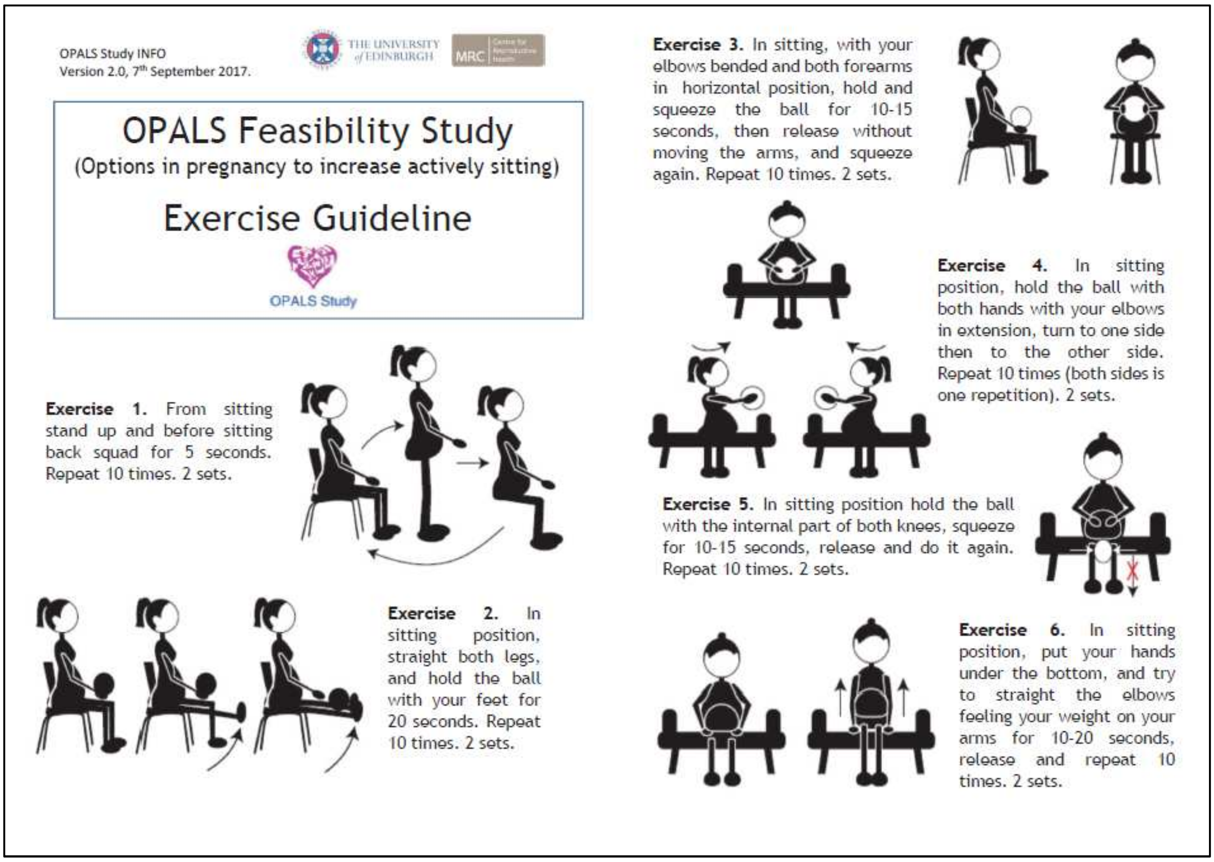
We were uncertain about the knowledge of obese pregnant women about sedentary behaviour, as well as about the willingness of morbidly obese pregnant women to exercise during pregnancy. Using a questionnaire, we observed that most of the severely obese pregnant women who participated in the first phase of the study were not aware of what sedentary behaviour is, but were interested in exercising during the time spent sedentary. That finding allowed us to go on looking for alternatives to offer morbidly obese pregnant women to encourage them to be more active during pregnancy.

According to the scarce evidence, most of the interventions with obese pregnant women based on physical activity have had no success, in terms of not being able to reduce pregnancy risks among participants in the intervention groups (Poston L et al., 2015). It has been observed that obese women have a lack of commitment to exercise (Nascimento S et al., 2011), which might be explained by the several barriers they have to be active, such as lack of information, and support, as well as apprehension on safety for the baby (Denison FC et al., 2015).

Obese pregnant women still require solutions to improve the pregnancy outcomes, and regular physical activity is still an interesting method to contribute to minimising the adverse effects of obesity during pregnancy. Bearing in mind all the known barriers which are preventing obese pregnant women to be more active, new, practical, suitable, and effective strategies are needed. Following suggestions from other researchers (Ong MJ et al., 2009), we thought in designing a home-based exercise plan, for, but also with morbidly obese pregnant women. We invited patients attending the Antenatal Metabolic Clinic to take part, contribute, and get involved in the design process, sharing their own experiences, and perspectives. Participants showed real interest in helping us to design an effective exercise intervention, and understood very well the role they were playing in the study, cooperating, constructively and accurately.

After the design process, in which 23 women took part, an exercise intervention was designed, based on six exercises, to be performed while sitting, for at least three times a week, and during 12 weeks as a minimum, aiming to exchange time sedentary with active sitting time **(Figure 17)**. The intervention was designed to be completed in about 45 to 60 minutes, involving most of the big muscle groups. Participants who take part in the exercise intervention would be benefited by decreasing time sedentary, increasing the energy expenditure, but also by gaining muscle mass in the longer term, which would also contribute to increase the basal metabolic rate, and indirectly the total energy expenditure.

Figure 17. OPALS Study Exercise Guideline.



We are aware that our study has limitations. The lack of an objective method to assess the intensity of the proposed exercise intervention might be considered as a weakness, however the reliability of objective methods, such as heart rate devices, or accelerometers has not been demonstrated with morbidly obese subjects. Further, perceived intensity scales are the most commonly used methods to assess intensity in all populations (Scherr J et al., 2013; Williams N, 2017). A strength of our study is that we continued recruitment until data saturation. The specific population for which the intervention is targeted, morbidly obese pregnant women, might be considered as a limitation or a strength. We consider this as a strength as this particular group has not many options to be active, and the strategies meant for other populations do not match their necessities, abilities and capacities. On the other hand, it might be a limitation, since the intervention might not be effective and suitable for different populations. Another strength of the study lays on placing participants as protagonists, which has been essential, precisely because of the physiological, anatomical, and psychological differences that morbidly obese pregnant women present compared with other pregnant women, but also because of the differences on the impact that exercise itself might have on them. However, having designed the exercise strategy with morbidly obese pregnant women does not assure the success of the study, which is the reason why before proceeding with a controlled trial, we next aimed to study the feasibility of the intervention.

By including participants in the study design we hope to have built an effective, challenging, interesting, feasible, and safe method to increase the energy expenditure, and reduce sedentary behaviour, for morbidly obese pregnant women, offering also, the chance to exercise at home. In the next chapter we aimed to study the feasibility of this exercise intervention among morbidly obese pregnant women, to assess adherence, commitment, beliefs, and motivations.

Chapter VI. Options in Pregnancy to increase ActiveLy Sitting (OPALS) feasibility study

Chapter VI. Options in Pregnancy to increase ActiveLy Sitting (OPALS) feasibility study.

6.1. Introduction

Obesity is increasing around the world, also among pregnant women (Denison FC et al., 2014; Fitzsimons KJ & Modder J, 2010; Heslehurst N et al., 2008; Huda SS et al., 2010). A negative association between obesity and pregnancy outcomes for mothers and infants has been widely described (Lisonkova S et al., 2018; Norman JE & Reynolds RM, 2011; Reynolds RM et al., 2013; Schummers L et al., 2015; Scott-Pillai R et al., 2013), and that those risks are greater with a higher BMI (Blomberg M, 2014; Denison FC et al., 2014). Therefore morbidly obese women are at very high risk.

The systematic review conducted as part of Chapter II showed that pregnant women spend half or more of their time awake in sedentary activities (Fazzi C, Saunders DH, Linton K, Norman JE, & Reynolds RM, 2017). Also, a negative association has been reported between time sedentary and pregnancy outcomes. With that framework, effective strategies to help obese pregnant women are required to reduce the risks and the consequences of obesity and sedentary behaviour during pregnancy.

No interventions with obese pregnant women with the specific aim to reduce time sedentary were found. Conversely, many interventions to increase physical activity in overweight or obese pregnant women have been found, offering different strategies, some also involving diet advice, such as the PEARS randomised controlled trial with overweight and obese pregnant women (Kennelly MA et al., 2018), the Limit randomised trial, also involving overweight and obese pregnant women (Dodd

J et al., 2014), the Upbeat Study involving only obese pregnant women, also based on diet and physical activity (Poston L et al., 2015), and the ETIP trial which also included obese pregnant women (Garnæs KK, Mørkved S, Salvesen Ø, & Moholdt T, 2016). However, in most cases, interventions based on diet and physical activity have failed in improving results among participants in the intervention groups, at least on the primary outcomes.

Considering trials focusing on physical activity alone, there are different examples, with different approaches. For instance in another randomised controlled trial involving obese pregnant women, researchers aimed to study the effect of a medical supervised exercise intervention, to decrease the mean levels of fasting plasma glucose at 24-28 weeks of gestation (primary outcome). Women in the study group (n=43) were invited to take part in the intervention, which was based on 10 minutes warm-up, 50-60 minutes of exercising, 15-20 minutes of resistance or weights, same time of aerobic training, and 10 minutes cold-down, three times per week along gestation, and until six weeks after delivery. Women in the control group (n=43) received routine prenatal care. No differences between groups were observed in the mean fasting plasma glucose (control 90.0±9.0 mg/dL; intervention 93.6±7.0 mg/dL; p=0.13). Also no differences were observed on the development of GDM between groups (control 48.8%; intervention 58.1%; p=0.51). However, the number of obese women in the study group that gained excessive gestational weight was significantly lower than the number of women in the control group, at 36 weeks of gestation (23.5% v/s 45.2% respectively; p<0.05). Women in the intervention group attended on average one class per week, which according to the authors was better than in other studies with a similar population (Daly et al., 2017). In another randomised controlled trial with pregnant women, the authors aimed to study the effect of an exercise intervention on gestational hypertension and macrosomia, as the primary outcomes. Three hundred eighty-two pregnant women were randomly assigned to the study group, and 383 women to the control group who received standard care. The exercise intervention included toning, pelvic floor exercises, light resistance, and aerobic dance. Even when the intervention was not meant specifically for obese pregnant women, the adherence rate, was similar for all BMI categories. After stratifying for BMI, the incidence of gestational hypertension was significantly lower among the study group, the proportion of excessive weight gain was also lower among the study group, the incidence of GDM was significantly lower among women in the study group, and the rate of macrosomic babies was also significantly lower among mothers in the study group compared with women in the control group. Compliance reached more than 80% (Barakat R et al., 2016). In other example, a randomised controlled trial was conducted involving overweight and obese pregnant women. Participants in the study group (n=132) took part in regular stationary supervised cycling exercise at different intensities, whilst the control group received standard care (n=133). The incidence of GDM was significantly lower among the study group (22%) compared with the control group (40.6%). It is important to highlight the 90% of compliance, women in the study group participated in more than 80% of the cycling program. The authors acknowledged that the main strength of the trial was the supervision, which guaranteed the high level of adherence, and ensured the amount and intensity of the exercise (Wang C et al., 2017).

It has been suggested that home-based interventions with overweight and obese pregnant women based on low to moderate-intensity exercise might achieve better compliance rates, where participants feel more comfortable (Ong MJ et al., 2009). Nevertheless, with morbidly obese pregnant women, it is not clear whether or not home-based strategies might improve outcomes and increase compliance. In a randomised controlled trial involving overweight and obese pregnant women researchers used a home-based exercise intervention with stationary bicycles. The exercise group involved 38 women, and the control group included 37 women. The primary outcome was infant birthweight. No differences were found between groups on infant birthweight, GWG, quality of life in any dimension, pregnancy outcomes or maternal body composition after delivery. Compared with the control group, a significant improvement on aerobic fitness was observed among the study group ($p =0.019$). Low compliance with the intervention was observed, 33% of the exercise sessions were accomplished. A sensitivity analysis was also conducted showing that higher compliance was associated with better fitness ($p=0.002$), lower resting heart rate ($p=0.014$), greater physical quality of life ($p=0.034$), lesser fat mass ($p=0.007$), lower BMI ($p=0.035$), and higher oxygen consumption ($p=0.015$) (Seneviratne SN et al., 2016).

The examples showed that there are several factors involved in the design of an intervention, such as the approach, compliance and supervision, and that all are important and might affect the outcomes for better or worse. To conduct a valid and effective study, evaluating feasibility might be fundamental in order to conduct a specific strategy with certain population aiming to complete it successfully, in terms of cost, timelines, and targets (Rajadhyaksha V, 2010). In particular for this study a feasibility study was necessary to calculate essential factors before designing a proper randomised controlled trial, such as the recruitment rate, adherence, and compliance.

In the previous chapter, an active sitting intervention was designed aiming to reduce sedentary behaviour in severely obese pregnant women; the feasibility of the same intervention is studied in the present chapter.

6.2. Aim

To assess the feasibility of an active sitting exercise intervention for morbidly obese pregnant women to reduce sedentary time and increase energy expenditure.

To assess participants' responses (recruitment rate, adherence, compliance, perceived barriers and benefits).

6.3. Methods

6.3.1. Ethics Approval

The OPALS Study received ethical approval from the Research Ethics Committee on 11th September 2017, reference 17/SS/0101, protocol number AC17053, Integrated Research Application System (IRAS) project ID 228472 and Lothian Research and Development (R&D) approval number 2017/0248 on 26th September 2017.

6.3.2. Setting

The study was conducted at the Antenatal Metabolic Clinic, Royal Infirmary of Edinburgh, Edinburgh between 10th October 2017 and 5th June 2018.

After confirming eligibility, Tommy's midwives during the first antenatal appointment gave the OPALS Study Information Sheet to potential participants and briefly explained the intervention. Interested patients were referred to the researcher, who held a personalised interview, where patients were explained all aspects of the exercise intervention in more depth. Those who agreed to take part signed the consent form and received the document wallet including the participant's copy of the consent form, the Participant Information Sheet, Exercise Strategy Guideline, the Exercise Strategy Activity Diary, a laminated summary of the exercises with a magnet, and the soft ball required to perform the exercises.

After 12 weeks of the first interview with the researcher, participants were contacted by a text message or a call, to ask them to please bring the Exercise Strategy Diary to the next appointment in the Antenatal Metabolic Clinic, where the researcher contacted them, retrieved the diaries and administered the OPALS Feasibility Questionnaire.

6.3.3. Sample

6.3.3.1. Inclusion criteria

- Body mass index (BMI) of 40 Kg/m^2 or over.
- During the first trimester of gestation (less than 20 weeks of gestation).
- Between 16 and 50 years old.
- With a healthy singleton pregnancy.
- Ability to provide informed consent.
- Attending the Tommy's Antenatal Metabolic Clinic.

6.3.3.2. Exclusion criteria

- Have any contraindication to perform the proposed exercises, according to the consultant.

6.3.3.3. Sample size

A pragmatic decision was made for the sample size, mostly based on the thesis schedule. We aimed to recruit as many women as possible until the first week of March 2018, considering that the intervention was designed to last 12 weeks, and to finish the thesis on time according to necessary deadlines (Whitehead AL, Julious SA, Cooper CL, & Campbell MJ, 2016).

6.3.4. Data collection

6.3.4.1. Participants' Information Sheet

An information sheet was given to all potential participants by the midwives, before women consented to take part in the intervention.

The information sheet detailed all aspects of the study, including the purpose of the intervention, what the intervention involved, disadvantages and benefits of taking part, where to complain if necessary, what would happen after the study finishes, who to contact for more information, etc.

6.3.4.2. OPALS Study Consent form

During a personalised interview with the researcher, after showing interest in taking part in the study, participants had time to read carefully and sign the OPALS Study Consent Form in two copies, both of which were also signed by the researcher at the same time. In the consent participants agreed to take part, to complete the Exercise Strategy Diary daily, agreeing that some personal information might be seen by part of the study team, and agreed for the storage of their data. Participants also provided their phone number to be contacted by the researcher, choosing their preferred approach, text or call.

6.3.4.3. General Practitioner Information Sheet

An information sheet for every recruited woman's general practitioners (GP) was sent to inform that the patient was taking part in the OPALS Feasibility study, and briefly what the intervention involved.

6.3.4.4. Exercise Strategy Guideline

The OPALS Exercise Strategy Guideline provided information to the recruited participants regarding the risks associated with obesity and sedentary behaviour during pregnancy, and how an exercise intervention might help by increasing their energy expenditure and reduce the time they spend sedentary. It also described in detail each of the six exercises included in the intervention, with drawings. The Strategy Guideline was provided to the participants during the first interview with the researcher, where the researcher demonstrated the exercises and performed them with the participant following the guideline.

6.3.4.5. Exercise Strategy Activity Diary (**Appendix 7**)

The OPALS Exercise strategy Activity Diary was a 32 page booklet specially designed for the OPALS Study, which included instructions on how to complete the diary, and then 14 weeks including each day from Monday to Sunday on the top row, as well as the six exercises on the left column, with the corresponding space to write the number of repetitions, time to hold (in seconds), and number of sets. Participants were instructed to complete it daily, according to their performance. Additionally, for every week, there was a space to write any extra comments. The diary was handed to the participants during the first interview at baseline, where the researcher explained how to fill it.

6.3.4.6. OPALS Feasibility Questionnaire (**Appendix 5**)

The feasibility questionnaire was designed to be administered once the 12 weeks of intervention had finished. It consisted of 15 questions asking about women's experience with the intervention. Five were open questions, and the 11 remaining had options to choose from. The questionnaire was self-administered, and was completed by women whilst in the waiting room prior to their appointment in the Antenatal Metabolic Clinic.

6.3.5. Exercise intervention

The exercise intervention consisted of six exercises involving most of the big muscle groups. Five exercises were designed to be performed while sitting, and one standing (squats). Four exercises required a medium size (22 cm diameter) soft ball which was provided. Three exercises were mainly for legs, two for arms and one for abs. All six exercises were planned to be done in 10 repetitions and two sets with a total recovery pause between sets. Participants were asked to perform the intervention for at least 12 weeks, three or more times per week. Doing the complete intervention took between 45 to 60 minutes, depending in the numbers of repetitions or time holding, as most of exercises had suggested ranges. Length of time also depended on the time each participant took to recover between sets and exercises.

6.3.5.1. Materials

- A medium size (22 cm diameter) soft ball (provided).
- A steady and sturdy chair.

6.3.6. Data analysis

The feasibility results of the exercise intervention were analysed descriptively, considering mostly the Activity Diary data and the Feasibility Questionnaire. The main focus of the analysis was set on quantifying recruitment rate, defined as the proportion of women who consented in taking part in the intervention from all women approached. Adherence was defined as to what extent the participants agreed with the intervention (Chakrabarti S, 2014), and compliance was defined as at what extent the participants effectively followed what were instructed to do (Chakrabarti S, 2014). A qualitative analysis was also conducted using data obtained by the observations and comments. Specifically it was examined the number and proportion of women completing the intervention; also the number and proportion of women who declared to keep on doing the exercises. The number and proportion of participants who quitted the intervention were quantified, along with the reasons to quit, which were also registered. It was identified which exercises were the most difficult and why. Also was summarised the qualitative information obtained, such as general perceptions, or personal feedback regarding the intervention in general, but also on each exercise.

For the analyses, only women who performed the exercises intervention for at least six weeks were included.

6.4. Results

6.4.1. Intervention

After approaching 69 women meeting the eligibility for inclusion, 30 women were recruited (recruitment rate=43.5%). Of these, two women did not attend their appointment in the Clinic to return the diary and administer the completion questionnaire, leaving a total sample of 28 subjects. The reasons not to take part are shown in **Figure 18**.

Six (21.4%) women completed the intervention for 12 weeks or more. Five (17.8%) women performed the intervention for six to 11 weeks. Three (10.7%) did not start immediately after the first interview, but they started later and had done the exercises for only three to five weeks at the moment that the questionnaire was administered and the diaries collected. The other 14 (50.0%) women did not perform the intervention for more than two weeks, of these, one said she would keep on doing it. Of all women (n=28) 60.7% (n=17) of women returned the Exercise Strategy Activity Diary, whilst 11 did not return the Activity Diary (39.3%).

6.4.2. OPALS Feasibility Questionnaire (Appendix 5)

On average women who completed six or more weeks of intervention (n=11), performed it for 11 weeks. Five were expecting their first child, and six had children, of those, five had one child, and one had two. On average they practised the exercises four times per week. Eight (72.7%) women did the exercises once per day, while three (27.3%) did them more than once. Nine (81.8%) participants thought that doing the intervention five times per week was not too much, and two (18.2%) thought it was too much. Women reported that on average four to five times per week should be the best frequency option. Ten women (90.9%) said that the intervention was enjoyable, one said “don’t mind” (9.1%). In the question “Will you keep on doing the exercises after 12 weeks?”, nine (81.8%) participants declared that would keep on doing the intervention, one did not reply, and one (9.1%) did not choose any of the options (yes or no), but wrote “maybe”. All women (100%) reported that it was easy to participate in the intervention and that it was easy to accomplish the instructions. For three (27.3%) participants nothing was difficult regarding the intervention. Exercise 6 (hold their own weight on the arms) was the most difficult for four (36.4%) of the participants. Two (18.2%) reported that the most difficult was to find the time to do the exercises. One of the participants said that Exercise 1 (squats) was the most difficult, one that leg exercises were the most difficult, and one said that to start with the intervention was the most difficult. Regarding the question if there was something missing, ten (90.9%) participants did not find anything missing, one (9.1%) said yes, but did not answer what. Nine (81.8%) women declared that after a while of practising the exercises their body performance improved, one (9.1%) said it did not improve, and one (9.1%) was not sure. Ten (90.9%) women reported that the exercises made them feel better, and one (9.1%) was not sure. Ten (90.9%) women believed that the diary was helpful, while one (9.1%) was not sure.

The same analysis but including only women who completed the suggested 12 or more weeks of intervention (n=6), showed that on average women performed it for 13 weeks. Four were expecting their first child, and two had one child. On average they practised the exercises four times per week. Four (66.6%) women did the exercises once per day, while two (33.3%) did them more than once. Five (83.3%) participants thought that doing the intervention five times per week was not too much, and two (16.7%) thought it was too much. Women reported that on average four times per week should be the best number of times per week to perform the intervention. In the question “Was it enjoyable to perform the exercises?”, five women (83.3%) said that the intervention was enjoyable, one did not choose any of the options, instead wrote “don’t mind” (16.7%). All six participants (100%) declared that will keep on doing the intervention. All women (100%) reported that it was easy to participate in the intervention and that it was easy to accomplish the instructions. For two (33.3%) participants nothing was difficult regarding the intervention. Exercise 6 was the most difficult for three (50%) of the participants. One of the participants (16.7%) said that exercise 1 was the most difficult, and one (16.7%) that leg exercises were the most difficult. Regarding the question if there was something missing, five (83.3%) participants did not find anything missing, one (16.7%) said yes, but did not answer what. Five (83.3%) women declared that after a while of practising the exercises their body performance improved, and one (16.7%) said it did not improve. All (100%) women reported that the exercises made them feel better, the same (100%) reported that the diary was helpful.

Analysing the answers among those participants who did not complete at least the half of the intervention, and the reasons were variable, three women (21.4%) said that the problem was finding the time to do the exercises. Three (21.4%) avoided the exercises due to pelvic pain. Two (14.3%) women said that the reason not to complete the intervention was that were too busy. Also two (14.3%) said that the reason was a sickness. The other reasons that only one participant (7.2%) mentioned not to complete with the exercise plan was that it was tedious, extreme anxiety, had problems to breathe, to keep doing it for 12 weeks, and tiredness. One participant did not respond.

Figure 18. Flow chart of recruitment process

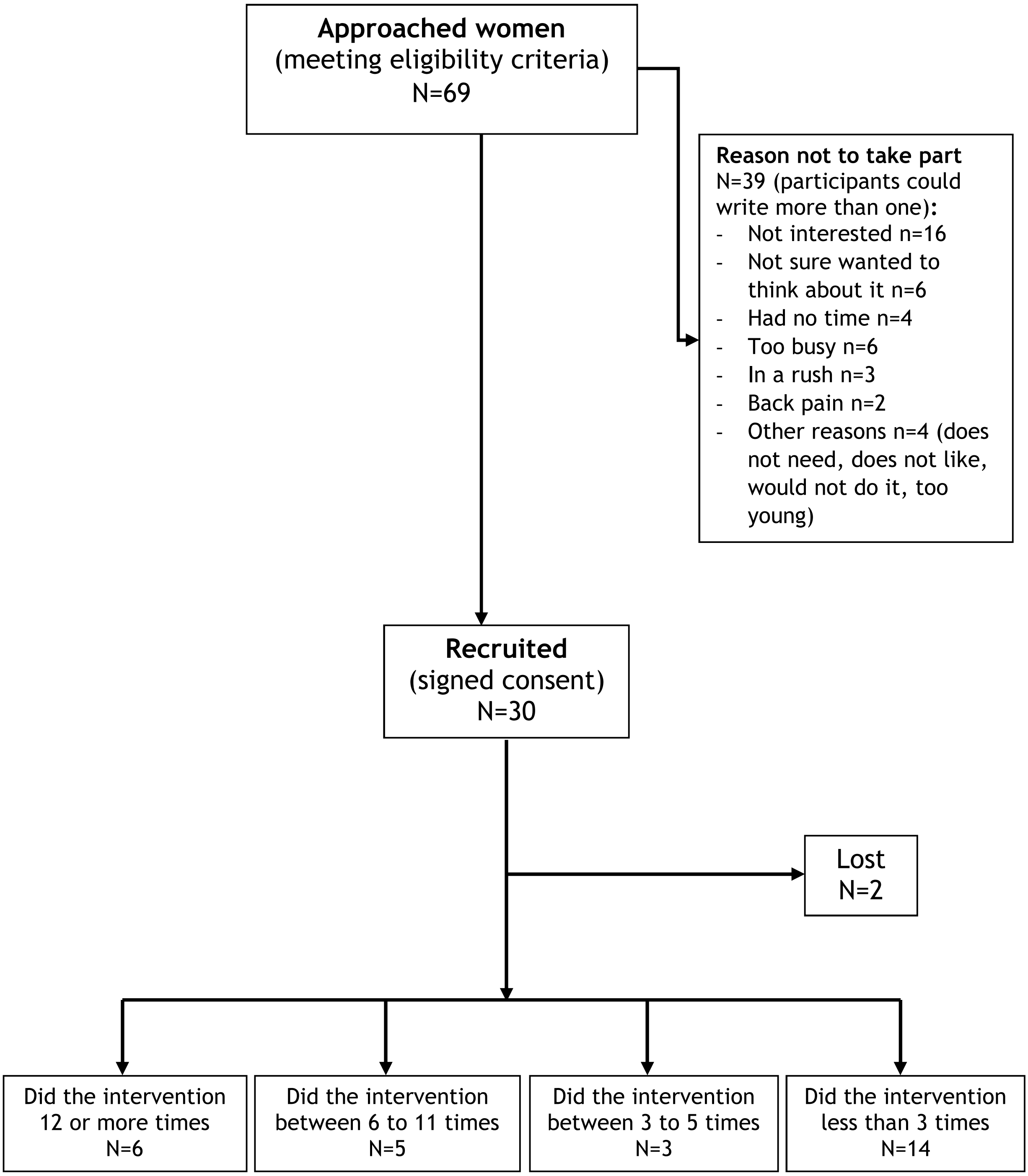


Table 10. OPALS feasibility questionnaire main results

Regarding the intervention	Participated for 6 or more weeks (n=11)	Participated for 12 or more weeks (n=6)
Time performing on average	11 weeks	13 weeks
First child	5 (45.4%)	4 (66.7%)
Had children	6 (54.6%)	2 (33.3%)
Frequency per week on average	4 times per week	4 times per week
Once per day	8 (72.7%)	4 (66.7%)
More than once per day	3 (27.3%)	2 (33.3%)
Enjoyable Yes	10 (90.9%)	5 (83.3%)
Will keep on doing	9 (81.8%)	6 (100%)
Easy to participate and follow the instructions	11 (100%)	6 (100%)
Preformance improved Yes	9 (81.8%)	5 (83.3%)
Made feel better	10 (90.9%)	6 (100%)
The diary was helpful Yes	10 (90.9%)	6 (100%)

Based on the feedback provided by the participants, some of them took the intervention as an opportunity to do something positive for their offspring by reducing the risks that their obesity implies for their babies. Some of them decided to take part to compensate the culpability they feel for being obese. Others felt somehow linked with the researcher and kept on doing the intervention not to let her down.

Although most of the women understood that the intervention might have been good for them and their babies, and signed the consent hoping to be able to commit with the intervention for the best, being pregnant is not the best, and being in addition severely obese makes it even more difficult. Besides some women had to keep on working, or had more children to care of, or felt too tired, and others in addition had pain, all that makes it somehow understandable that they could not fulfil the

12 weeks exercise intervention. From that point of view, of 28 women, 11 completed at least six weeks of the exercise programme and declared to keep on doing it. Which is not disappointing at all, on the contrary, is satisfying and even promising.

6.5. Discussion

An active sitting exercise intervention for morbidly obese pregnant women to reduce sedentary time and increase energy expenditure was conducted to assess the feasibility. Thirty morbidly obese pregnant women were recruited to take part in a based-home exercise intervention, of these two women did not show up for final data collection. Only 21.4% (n=6) completed the 12 suggested weeks of intervention, meanwhile 39.2% (n=11) completed six weeks of intervention, half of what was suggested. These is similar to what was observed by Seneviratne et al., also using a home-based exercise strategy with overweight and obese pregnant women, but achieving a low compliance (Seneviratne SN et al., 2016).

After the obtained results is possible to state that the exercise strategy is feasible. The study has shown what to expect for future studies using the same or an improved intervention, in order to design an appropriate randomised controlled trial, demonstrating the numbers that are needed for both recruitment and completion of the intervention in order to calculate the sample size properly.

The main strength of the exercise intervention was the inclusion of morbidly obese pregnant women in the design, which allowed us to improve and test the intervention during the design process, making it appropriate and practical. Another strength is the home-based approach, which regardless of the low compliance, was well received by the participants, and seemed suitable for morbidly obese pregnant women. Another strength of the study was the use of the time sedentary to introduce an exercise intervention, besides, the fact that the intervention can be performed while sitting was also convenient for the participants, as they were able to do other things at the same time, like watching television. The minimal and cheap materials needed to perform the exercise intervention is another strength, and finally the simplicity of the exercises, which were chosen because they did not require a complex technique, and regarding that, which was corroborated by the participants who reported that it was easy to follow the instructions. The main weakness of the intervention is the lack of an objective measurement to study energy expenditure and time spent sedentary. Also the lack of supervision is a weakness, as some women needed to be encouraged and required more support to complete the intervention. Another identified weakness was in relation to Exercise 6, which involved holding the whole weight with the arms for 20 seconds, and was reported by participants to be the most difficult. One said that her arms were too short to do it, and two mentioned that they did not do it.

It is not clear why the problem with exercise 6 was not observed at the design stage. During the design process when women did the exercises with the researcher in the interview, they did not experience any discomfort or difficulty. Similarly, during the intervention, when practiced the exercises in the first interview with the researcher, no problems with exercise 6 were identified. Apparently, participants experienced problems at home, when they had to perform the exercises on their own, and despite being told to contact the researcher if necessary, no one did. Consequently, the potential problem underneath, was the lack of communication between the researcher and the participants during the intervention. If the researcher would have known about the problem with exercise 6, she would have offered an alternative exercise.

Involving participants in the design of an intervention might be helpful and practical, nevertheless exercises may still need to be individually tailored to enable maximum participation. The problem might have been just discomfort or wrong technique, however having options might help participants to overcome individual impairments, working the same muscles and also involving the own weight. Also, the lack of warm-up and a cool-down as part of the intervention are acknowledged as weaknesses and should have been included as part of the programme.

Hopefully this study will lead to new and better studies, ideally a randomised controlled trial which allow to study the effect of the exercises intervention on pregnancy outcomes, such as the incidence of GDM, gestational hypertension, preeclampsia, and GWG; and also for the new-born, such as birthweight.

Chapter VII. Discussion

Chapter VII. Discussion

7.1. Discussion

The background regarding pregnant women and the prevalence of sedentary behaviour among them, as well as the associations between sedentary behaviour and pregnancy outcomes were exposed through a systematic review published in March 2017 (Fazzi C et al., 2017). The review was updated in April 2018. It was the first systematic review studying sedentary behaviour during pregnancy and showed that pregnant women spend at least half of their time awake on sedentary activities, also that too much time sedentary during pregnancy might be associated with adverse outcomes for pregnancy. It was also observed that research on the same topic has increased in the last years, as the number of published papers increased considering the period between October 2015 and April 2018 (18 papers), compared with the 26 publications that were found until October 2015 indicating that interest is rising in researching about sedentary during pregnancy. Despite the fact that the 'Sedentary Behaviour Research Network' (SBRN), the organization that centres the focuses specifically on the impact of sedentary behaviour in health, to help health professionals and researchers, has defined sedentary behaviour as waking activities expending 1.5 METs or less, while reclining, lying or sitting (Tremblay MS et al., 2017), a definition that is widely used, there are still discrepancies between studies, mostly on the assessment methods, but also on the thresholds to classify activities as sedentary based on intensity or energy expenditure, and in the definition to classify subjects as sedentary in terms of prevalence. Those discrepancies make it difficult to set agreement or to make comparisons between findings.

In the cross-sectional study that was performed in Chapter IV, and which was published in May 2018 (Fazzi C et al., 2018), it was shown that regarding energy expenditure, morbidly obese pregnant women expended significantly more energy in total and in sedentary activities than lean pregnant women. However, in terms of the proportion of time spent in sedentary activities both groups behaved similarly. To the best of our knowledge, it was the first study assessing energy expenditure including morbidly obese and lean pregnant women.

Prescribing exercise for morbidly obese people is difficult, firstly due to the higher risks that the effort means for them, but also because their performance and tolerance to exercise are different than for lean people. In addition, there was little in the literature offering ideas to design an appropriate and suitable exercise intervention for morbidly obese pregnant women. Based on others studies with obese pregnant women, and involving morbidly obese pregnant women (n=23), an intervention based on active sitting exercises was designed, including six exercises, five of them to be performed in a sitting position. All exercises were tested by the participants involved, as well as the number of repetitions, the time to hold an exercise, and the number of sets. In general, the experience of involving subjects in the design was helpful and practical. In fact what was expected in theory was far different than the last result which was obtained by the participants' experience. The first proposal intervention underestimated participants' capacities. This might have happened due to the assumption that obese people are less tolerant to exercising. Otherwise, most of the exercises included in the intervention are meant to be performed sitting, which should somewhat annull the effect of the weight, reducing the difficulty and increasing participants' ability to execute the exercises.

To our knowledge, there was nothing in the literature involving morbidly obese pregnant women in an intervention with physical activity. Therefore it was not clear what to expect for the exercise intervention for morbidly obese pregnant women, designed in Chapter V. Recruited women (n=30) were asked to perform the exercise intervention for at least 12 weeks, and not less than three times per week. The results revealed that most of recruited morbidly obese pregnant women did not fulfil the 12 weeks intervention during pregnancy. Therefore as it has been the first time, now it is possible to have an idea of what to expect in the future when involving morbidly obese pregnant women in interventions to encourage them to be more active. Earlier experiences in the same Antenatal Metabolic Clinic showed no participation. One intervention offered aqua aerobics but women did not attend. Similarly a walking group strategy was proposed, but no participants attended to the sessions.

7.2. Strength and Weaknesses

In general most of the work developed in this thesis was novel, offering for the first time a panoramic view of the situation involving sedentary behaviour among obese pregnant women.

One of the main strength of this thesis was the method employed to design an exercise intervention shown in Chapter V, involving participants. When participants are involved in the design their feedback might be immediate, which allows to make amendments and promptly improve the design. Getting feedback face to face has been positive, realistic and effective. It might also have been important that participants tried the exercises alone with the researcher, which made them feel comfortable and offered them the possibility to communicate openly, without feeling embarrassed about doing something wrong.

Another strength observed also in the exercise intervention strategy in Chapter VI, was to empower participants to take care of themselves, by teaching them to do the exercises on their own, which combined with the home-based approach gave them the chance to take care of themselves and their developing babies at their homes. At home participants felt safe and comfortable, and they did not need to go anywhere else, saving time and avoiding transportation. Other strength of the exercise intervention in Chapter VI was that most of the exercises were meant to be done in a sitting position, therefore their weight did not affect their performance.

To target teaching participants to do the exercises on their own at home, In Chapter VI, which was considered a strength, might also be a weakness as some participants probably needed more supervision or encouragement to fulfil the intervention. More supervision also might help to retrieve more data on the exercise intervention performance, to improve the intervention and to assess feasibility.

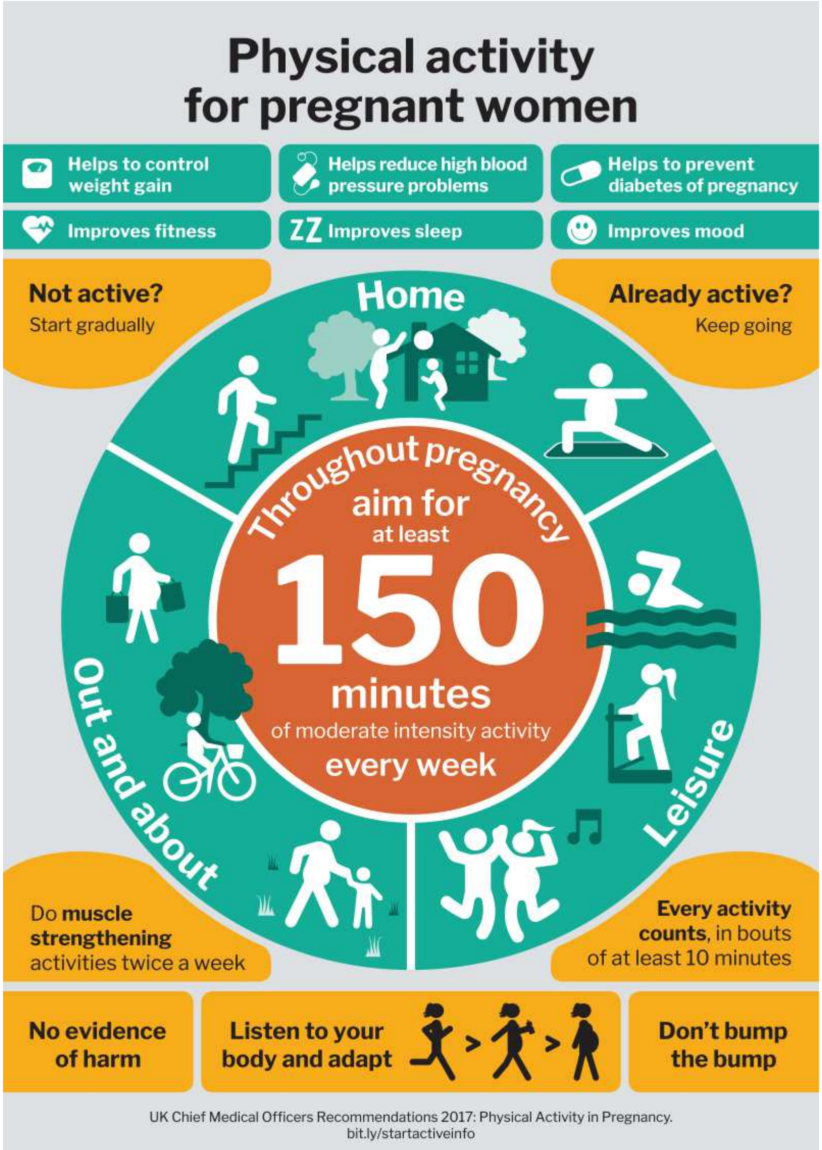
Another weakness was the lack of an objective method to assess the accomplishment of the same exercise intervention, which would have helped considerably to assess feasibility.

7.3. Gaps in the Literature

This thesis has shown that even though the number of morbidly obese pregnant women has increased, and it is known that the risks of obesity are greater for morbidly obese than for leaner pregnant women, there are still scarce data regarding morbidly obese pregnant women and methods to reduce the risks associated with obesity during pregnancy.

In addition, the information given to obese pregnant women to reduce health risks is usually not clear and not practical. For instance, the information included in infographics (**Figure 19**) like the one designed by the UK Chief Medical Officers Recommendations “Physical activity for pregnant women” (Smith R et al., 2018), is not realistic and certainly not useful for pregnant women in general, but even worse for morbidly obese pregnant women. The Nice Guidelines for weight management (NICE, 2010) are better in terms of information as there are specific recommendations for women with BMI over 29Kg/m^2, however, these are meant for health professionals who help pregnant women. Nevertheless, in the NICE Guidelines, information on physical activity and sedentary behaviour is lacking, even for health professionals. For instance the NICE Guidelines recommend to encourage pregnant women to practice physical activity regularly, and to give practical and specific advice on physical activity to pregnant women; however do not explain how, and health professionals do not necessarily have the knowledge to give counsel on physical activity. The same NICE Guidelines suggest recommending pregnant women to minimise the time they spend sedentary but do not explain the reason, which might be another important thing to teach. Besides, the language of the NICE Guidelines is not clear enough or practical, i.e. it is not clear how intense is the moderate -intensity. To improve that, providing pregnant women with leaflets with clear drawings showing activities or exercises that they can do, including recommended number of repetitions, and a suggested frequency, might be a suitable alternative. Also explaining that moderate-intensity is the usual intensity of a quick walk pace, feeling their hearts accelerated, but being able to talk at the same time.

Figure 19. Physical activity for pregnant women



Professionals prepared to advise on physical activity in pregnancy are required. As there are dietitians available to help pregnant women and obese pregnant women, in particular, there should be physical activity experts to counsel obese pregnant women in what and how to exercise, or at least midwives should be instructed by experts on physical activity, to give an appropriate recommendation.

7.4. Future Directions

The combination of information and practical advice, and some supervision involving support and encouragement should be considered. Good quality and clear information is required, as it is important to teach morbidly obese pregnant women why their obesity is negative for their pregnancy, also why too much time sedentary is an unhealthy behaviour. Learning that will automatically encourage them to take care of themselves. However, practical advice on how to take care is also required, which should be provided using effective, practical and feasible strategies designed involving participants, aiming to empower morbidly obese pregnant women to take care of themselves, but also offering support and supervision to reinforce the compliance and involvement.

Much more must be researched focussing on sedentary behaviour and physical activity, specifically for morbidly obese pregnant women. Hopefully involving trials, aiming to improve the treatments and the outcomes around morbidly obese pregnancies. New interventions with morbidly obese pregnant women could use this thesis as a model, copying the strengths and improving the weaknesses.

For a next study the same design methodology that was employed in this thesis, involving participants in the design, would be employed. A similar exercise intervention for morbidly obese pregnant women to reduce the time they spend sedentary and increase their energy expenditure would be the main approach. Most of the exercises included in the intervention conducted in this thesis would be the same, but some might change and/or alternatives would be proposed. Some flexibility exercises might be also added. A five to 10 minutes warm-up section and a five to 10 minutes cool-down section would be added before and after the main exercise section, respectively. The most important is that more support and supervision would be required in a new exercise intervention with morbidly obese pregnant women, to improve the commitment, retention rates, and the adherence. That might be achieved by increasing the communication between participants and researchers along the intervention. The method to communicate would be discussed with the participants in the design process and in the beginning of the intervention, as part of the consent, including different alternatives, such as calls or text messages with general supportive messages, or with personalised messages.

Hopefully, in the future, more researchers will take this experience as a basis for interventions with morbidly obese pregnant women, and will be able to keep on researching conducting high quality randomised controlled trials involving better interventions.

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Appendices

Appendix 1

Sedentary behaviours during pregnancy: a systematic review.

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Sedentary behaviours during pregnancy: a systematic review

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Abstract

Background: In the general population, at least 50% of time awake is spent in sedentary behaviours. Sedentary behaviours are activities that expend less energy than 1.5 metabolic equivalents, such as sitting. The amount of time spent in sedentary behaviours is a risk factor for diseases such as type 2 diabetes, cardiovascular disease, and death from all causes. Even individuals meeting physical activity guidelines are at a higher risk of premature death and adverse metabolic outcomes if they sit for extended intervals. The associations between sedentary behaviour with type 2 diabetes and with impaired glucose tolerance are stronger for women than for men. It is not known whether sedentary behaviour in pregnancy influences pregnancy outcomes, but if those negative outcomes observed in general adult population also occur in pregnancy, this could have implications for adverse outcomes for mothers and offspring.
We aimed to determine the proportion of time spent in sedentary behaviours among pregnant women, and the association of sedentary behaviour with pregnancy outcomes in mothers and offspring.

Methods: Two researchers independently performed the literature search using 5 different electronic bibliographic databases. Studies were included if sedentary behaviours were assessed during pregnancy. Two reviewers independently assessed the articles for quality and bias, and extracted the relevant information.

Results: We identified 26 studies meeting the inclusion criteria. Pregnant women spent more than 50% of their time in sedentary behaviours. Increased time in sedentary behaviour was significantly associated with higher levels of C Reactive Protein and LDL Cholesterol, and a larger newborn abdominal circumference. Sedentary behaviours were significantly higher among women who delivered macrosomic infants. Discrepancies were found in associations of sedentary behaviour with gestational weight gain, hypertensive disorders, and birth weight. No consistent associations were found between sedentary behaviour and other variables such as gestational diabetes. There was considerable variability in study design and methods of assessing sedentary behaviour.

Conclusions: Our review highlights the significant time spent in sedentary behaviour during pregnancy, and that sedentary behaviour may impact on pregnancy outcomes for both mother and child. The considerable heterogeneity in the literature suggests future studies should use robust methodology for quantifying sedentary behaviour.

Keywords: Sedentary behaviours, Sedentarism, Pregnancy

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Background

Sedentary behaviours are activities that expend very low energy, close to the basal metabolic rate, without significantly increasing energy expenditure. This equates to activities such as sitting or lying, that utilise less than 1.5 metabolic equivalent units, or times the basal metabolic rate [1, 2]. Sedentary behaviours are thus distinct from lack of physical activity, although the latter is sometimes mistakenly used as a marker of sedentary behaviour in the literature [3].

Epidemiological studies have shown that in the general adult population, around 55 to 60% of time awake is spent in sedentary behaviours [4, 5]. In the UK, children, young people, adults and older adults, spend on average at least half of their waking hours being sedentary [6, 7]. In pregnant women the situation appears to be similar or even worse [8–12], although the literature has not been systematically reviewed.

The quantity of time spent in sedentary behaviours is a key risk factor for diseases such as type 2 diabetes [13], cardiovascular disease [14], metabolic syndrome [15] and death from all causes [14, 16, 17]. New evidence also suggests that sedentary behaviour has an adverse effect on mental wellbeing, including depression [3]. Importantly some studies have exposed that even when individuals meet physical activity recommendations, they are still at a higher risk of premature death and adverse metabolic health if they sit for extended intervals [2, 18–20]. Sedentary behaviours, mostly television watching, are also linked to high risk of obesity and type 2 diabetes in the general population, independent of physical activity levels [1, 20], and in some studies the associations between sedentary behaviours with type 2 diabetes and with impaired glucose tolerance were stronger for women than for men [18, 21, 22].

If the negative health outcomes associated with sedentary behaviour in the general population, also occur in pregnancy, this could have implications for development of cardiometabolic complications such as gestational weight gain, gestational diabetes mellitus and hypertension, as well as mental wellbeing. It is not known whether sedentary behaviour in pregnancy influences outcomes for the baby such as birthweight or gestation at delivery.

We aimed to carry out a systematic review of the literature investigating sedentary behaviours during pregnancy to determine:

a) the time spent in sedentary behaviours and the prevalence of sedentary behaviours among pregnant women, and
b) whether sedentary behaviours are associated with pregnancy outcomes in mothers and offspring.

Methods

Data sources and searches

The Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines were followed for the conduct [23], and the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines for the reporting of this systematic review [24]. The systematic review was registered in PROSPERO with the number CRD42015023611.

Two researchers (CF, KL) independently performed the literature search using 5 different electronic bibliographic databases: MEDLINE, EMBASE, Web of Science, CINAHL and SPORTDiscus. The strategy (Fig. 1) was developed using Boolean. In MEDLINE medical subject headings (MeSH) used were: pregnant women (used also for pregnant woman), pregnancy (used also for pregnancies and gestation), prenatal care and sedentary lifestyle (used also for sedentary lifestyles). In EMBASE, main terms used were: pregnant woman (used also for pregnant women), pregnancy (used also for child bearing, childbearing, gestation, gravidity, intrauterine pregnancy, labour presentation, pregnancy maintenance and pregnancy trimesters), prenatal care (used also for ante natal care, antenatal care and antenatal control), prenatal period (used also for antenatal period) and sedentary lifestyle (used also for sedentary life style). The following keywords were also used for plain text searching in all databases: pregnan*, gestation*, gravid*, antenatal, prenatal, sedentar*, sitting, television, screen-based, TV, watching and viewing. Recursive searching of reference lists of retrieved articles was performed to identify any additional studies (Additional file 1).

Studies were included if the sample considered pregnant women over 16 years old, and if sedentary behaviours (specified as watching TV, sitting or lying, low energy expenditure activities, etc.) were assessed at any point during gestation. Only published studies were included. There were no exclusions related to study design, language, ethnicity, socioeconomic status, parity or physical condition.

Two reviewers (CF, KL) independently assessed articles for inclusion according to the inclusion/exclusion criteria. After screening the titles and abstracts, the reviewers selected potentially relevant studies. If it was not possible to determine relevance from titles and abstracts, full texts were retrieved. Any disagreements that could not be resolved by consensus were discussed with a third reviewer.

Two reviewers (CF, KL) independently extracted relevant information on study characteristics, methodology, and study results using a data extraction form in order to determine whether the study reported the time that pregnant women spent in sedentary behaviours, the prevalence of sedentarism among pregnant women, and whether the sedentary behaviours were linked to pregnancy outcomes.

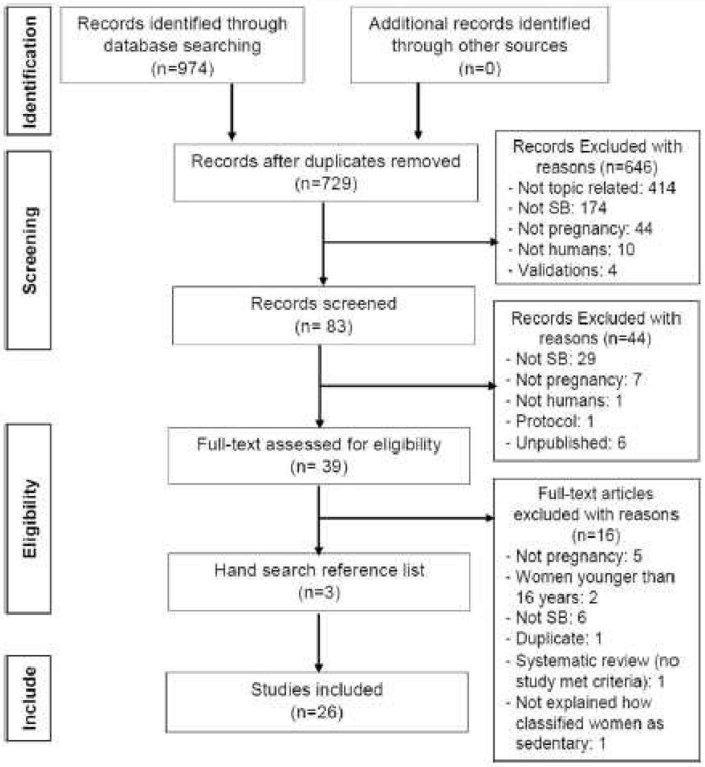

Fig. 1 Search strategy flow diagram

For presentation in the tables reporting time and proportion of time in sedentary behaviours, we standardised the outcomes (converted to the same units) in order to make them comparable. Due to the heterogeneity of outcome data, a narrative synthesis was developed.

Quality and risks of bias were assessed using objective criteria relating to sample population and recruitment, reliability of instruments, use of validated outcome measures, follow-up, risk of bias and data analysis, using a quality assessment instrument that was modified from the Grading of Recommendations Assessment Development and Evaluation (GRADE) Guidelines used in assessment of clinical trials [25–28]. A paper could attain a maximum score of 8, a score of 1–3 indicating poor quality, 4–6 intermediate, and 7–8 good quality.

Results

From 974 abstracts, 39 full text articles were assessed and 26 studies met the inclusion critera for the systematic review (Fig. 1).

Characteristics of included studies

Characteristics of the 26 included studies are displayed in Table 1. Seventeen were cohort studies [8, 12, 29–43], 7 were cross-sectional studies [9–11, 44–47], and 2 were randomised controlled trials [48, 49].

Most studies were carried out in the USA ($n = 11$) and Europe ($n = 9$), and the remaining were in China ($n = 2$), Africa ($n = 1$), Canada ($n = 1$), Australia ($n = 1$) and Singapore ($n = 1$). One study included couples (for the purpose of this review we only considered data from the women, not the men) [33]; 2 other studies included both pregnant and non-pregnant women (non-pregnant women were considered in this review when comparisons between the two groups were made) [33, 47]. Three studies were conducted in Hispanic pregnant women [34, 40, 43], and 1 in Latina pregnant women [36]. One study was conducted in nulliparous pregnant women, 1 in obese pregnant women [49], 1 in pregnant women with type 1 diabetes mellitus [41], and 1 in pregnant women with sedentary lifestyles [38]. Thirteen studies utilised objective methods to assess sedentary behaviours (accelerometers, pedometers, combined heart rate and accelerometer device, and indirect calorimetry), and 13 studies employed non-objective measures including 4 administrating the Pregnancy Physical Activity Questionnaire (PPAQ), 9 using another kind of survey or questionnaire (The Australian Women's Activity Survey, Modified version of the Kaiser Physical Activity Survey,

Table 1 Description of included studies (arranged alphabetically)

Author	Country	Number of participants	Study design	Criteria for inclusion	Assessment method		Definition of sedentary	Quality
Both, et al. (2010) [31]	UK	11759	Cohort	Pregnant women due to deliver between April 1st 1991 and December 31st 1992.	Self-reported questionnaire.	Non-objective.	Who declared being mostly sitting.	Intermediate
Chasan-Taber, et al. (2014) [40]	USA	1276	Cohort	Women of Puerto Rican or Dominican Republic heritage.	Modified version of the Pregnancy Physical Activity Questionnaire (PPAQ).	Non-objective.	Activities expending <1.5 METs.	Intermediate
Chasan-Taber, et al. (2015) [34]	USA	1240	Cohort	Women of Puerto Rico or Dominican Republic heritage.	PPAQ.	Non-objective.	The sum of the MET-h/day spent watching TV/videos or sitting/ standing at home, work, or during transportation.	Intermediate
Di Fabio, et al. (2015) [8]	USA	46	Cohort	Healthy pregnant women, including women between 18 and 45 years of age and singleton pregnancy.	- 7 day record diary. - SenseWear® Mini armband accelerometer. - ActivPAL™ Multi-sensor accelerometer.	- Non-objective. - Objective. - Non-objective.	Activities expending ≤1.5 METs (independent of nighttime sleep).	Intermediate
Evenson, et al. (2010) [37]	USA	1280	Cohort	Pregnant women ≥16 years of age.	The Behavioral Risk Factor Surveillance System (BRFSS).	Non-objective.	Two questions on TV watching and computer usage outside of work hours were used as SB indicators. Women were also asked if they were 'mostly sitting' during their usual daily activities.	Poor
Evenson, et al. (2011) [11]	USA	359	Cross-sectional	Pregnant women ≥16 years.	ActiGraph accelerometer.	Objective.	Activities expending <100 counts per minute.	Intermediate
Gollenberg, et al. (2010) [36]	USA	1006	Cohort	Latina ethnicity, age 16–40 years old, singleton pregnancy, and no prior participation in the study.	Modified version of the Kaiser Physical Activity Survey (KPAS).	Non-objective.	Hours spent TV watching per day and frequency of sitting at work.	Intermediate
Gradmark, et al. (2011) [47]	Sweden	101	Cross-sectional	Normal weight and overweight women without diabetes were studied.	Actiheart monitor.	Objective.	Epochs with valid heart rate data and zero accelerometry counts/min.	Intermediate
Hawkins, et al. (2014 Im.) [48]	USA	260	Randomized controlled trial	Women in their first trimester of pregnancy, between 16 and 40 years old, and at high risk for GDM.	Pregnancy Physical Activity Questionnaire (PPAQ).	Non-objective.	The amount of time spent watching TV or videos, or sitting or standing at home, work, or during transportation.	Good
Hawkins, et al. (2014 PA) [10]	USA	294	Cross-sectional	Women in the 2003–2006 NHANES study cycles who self-reported currently being pregnant, were 16 year or older, and who had available data on C reactive protein, physical activity, and SB.	ActiGraph accelerometer.	Objective.	Activities expending <100 counts per minute.	Intermediate
	UK	183				- Objective.		Good

Table 1 Description of included studies (arranged alphabetically) *(Continued)*

Hayes, et al. (2014) [49]			Randomized controlled trial	All obese (BMI ≥ 30 K/m^2) pregnant women.	- Acti-Graph accelerometer.		- Accelerometry: any minute with ≤100 counts/min.	
					- Recent Physical Activity Questionnaire (RPAQ).	- Non-objective.	- RPAQ, minutes spent on activities <1.5 MET.	
Hegaard, et al. (2010) [32]	Denmark	4558	Cohort	Danish-speaking pregnant women.	Self-reported questionnaires.	Non-objective.	Those who chose "mostly sitting" to describe most correctly her level of leisuretime activity.	Intermediate
Hegaard, et al. (2011) [35]	Denmark	4718	Cohort	Age ≥ 18 years, Danish speaking, singleton pregnancy, and intended spontaneous vaginal delivery.	Self-administered questionnaire.	Non-objective.	Those who answered: "Reading, watching television, or pursuing some other sedentary occupation", as the most appropriate description of her activities.	Intermediate
Hjorth, et al. (2012) [9]	Ethiopia	304	Cross-sectional	All pregnant women who attended routine visits at the antenatal care clinic.	- Actiheart (heart rate and movement device).	- Objective.	Energy expenditure ≤1.5 METs.	Intermediate
					- 24 h physical activity recall.	- Non-objective.		
Jiang, et al. (2012) [30]	China	862	Cohort	Pregnant women over 20 years old in a singleton pregnancy, and had no disease including gestational diabetes (GD), hypertension, heart disease, chronic renal disease, and other diseases restricting physical activity.	Pedometer.	Objective.	Less than 5000 steps per day.	Intermediate
Kamareswaran, et al. (2013) [41]	UK	10	Cohort	Type 1 diabetes, current insulin pump therapy, and a viable singleton pregnancy.	Actiheart (heart rate and movement device).	Objective.	Activities expending ≤1 MET.	Intermediate
Li & Zhao (2007) [46]	China	405	Cross-sectional	Pregnant women working in a sewing factory.	Self-reported questionnaire.	Non-Objective.	According to the job, women were assigned to the study group (persistent sedentary) or control group.	Poor
Loprinzi, et al. (2013) [44]	USA	206	Cross-sectional	All women who answered the 2003–2006 National Health and Examination Survey.	ActiGraph accelerometer.	Objective.	Activity counts between 0 and 99 counts/min.	Intermediate
Lynch, et al. (2012) [43]	USA	1355	Cohort	Women from the ambulatory obstetric practices at ≤20 weeks of gestation.	PPAQ.	Non-objective.	The amount of time spent watching TV or videos, or sitting or standing at home, work, or during transportation.	Intermediate
Oken, et al. (2006) [29]	USA	1581	Cohort	Women attending initial prenatal visit, who delivered live infants.	Modified version of the leisure time activity section of the Physical Activity Scale for the Elderly (PASE).	Non-objective.	Hours per week spent watching TV or videos.	Intermediate

Table 1 Description of included studies (arranged alphabetically) *(Continued)*

Padmapriya, et al. (2015) [42]	Singapore	1171	Cohort	Pregnant women aged 18 years and above attending first trimester antenatal dating ultrasound scan clinics.	Interview questionnaire.	Non-objective.	Hours spent on sitting plus hours spent on watching TV per day.	Intermediate
Reid, et al. (2014) [39]	Northern Ireland	100	Cohort	Healthy women, ≥16 years old, with singleton pregnancies, between 26 and 37 week gestation.	Body-media SenseWear Pro3 armband.	Objective.	Activities expending ≤1 MET.	Intermediate
Rhodes, et al. (2014) [33]	Canada	157	Cohort	The cohorts were couples without children, first-time parents during the first year of their parenthood experience, and second time parents during the first year of this parenting experience between the ages of 25 and 40 years of age.	GT1M Activity Monitor (accelerometer and stepcounter).	Objective.	Activities expending 0–100 average acceleration counts/min.	Intermediate
Ruifrok, et al. (2014) [12]	Netherlands	111	Cohort	Healthy pregnant women. Trial 1: nulliparous pregnant women without BMI restrictions, able to read, write and speak Dutch, and within their first 14 weeks of pregnancy; Trial 2: overweight and obese pregnant women at risk for gestational diabetes.	ActiTrainer accelerometer (Acti-Graph).	Objective.	Activities expending <100 counts/min.	Intermediate
Van Raaij, et al. (1990) [38]	Netherlands	18	Cohort	Healthy women judged by medical histories, blood pressure, hemoglobin concentration, and urine analysis.	- Open-circuit indirect calorimetry. - Physical activity diaries.	- Objective. - Non-objective.	Lying, sitting quietly or very light sitting activity, or light-to-moderate sitting activity.	Intermediate
Watts, et al. (2013) [45]	Australia	81	Cross-sectional	Pregnant women regardless of their pregnancy trimester.	The Australian Women's Activity Survey (AWAS).	Non-objective.	Frequency and duration of sitting behavior.	Poor

Behavioral Risk Factor Surveillance System, modified version of the leisure time activity section of the Physical Activity Scale for the Elderly, and other type of non-objective appraisal methods) (Table 2). The PPAQ has been validated among pregnant women, similarly 2 of the administered surveys were also validated among pregnant women, meanwhile 3 studies used validated questionnaires, but not validated among pregnant women. Finally, 4 of the questionnaires were not validated.

Amount and proportion of time spent in sedentary behaviours (Table 3)

The amount of time spent in sedentary behaviours was estimated in 8 studies using either objective [8–12, 30, 38, 44] or non-objective methods [42] (Table 3).

The time spent in sedentary behaviours during pregnancy assessed objectively, varied between 7.07 and 18.3 h per day. Of these studies 1 declared that sleeping was included [9], 2 stated that sleep time was not considered [8, 11], and the rest did not declare anything regarding sleep [10, 12, 44]. Meanwhile the study which assessed using a questionnaire found that women spent 2.4 h per day watching television and the mean of total sitting time was 8.6 h per day [42] (Table 3).

Among the 5 studies assessing the proportion of time spent in sedentary behaviours all used objective devices, finding that pregnant women spent more than 50% of their time (range 57.1 to 78%) in sedentary activities [8–12] (Table 3).

Definitions of sedentary behaviours

The definition of time spent in sedentary behaviours differed according to method of assessment. Studies that used accelerometers defined activities with less than 100 counts per minute as sedentary behaviours, while activities expending 1.5 metabolic equivalents or less was used for combined heart-rate and activity monitors. Meanwhile, non-objective methods focused mostly on television viewing and sitting time.

Table 2 Characteristics of included studies

	Number of studies	Participants (N)
Assessment tool		
Accelerometer	7	1356
Accelerometer and HR sensor	3	415
Pedometer	1	862
Other objective	2	118
Pregnancy Physical Activity Questionnaire (PPAQ)	4	4131
Other self-reported	9	26559

Prevalence of sedentarism among pregnant women (Table 4)

Five studies determined the prevalence of sedentarism among the pregnant population, all except 1 [30] used non-objective methods to assess activity behaviour, and all used their own cut-offs to classify women as sedentary. Two used the term "sedentary", defining this as <5000 daily steps [30] or considering women as 'sedentary' if they declared "watching television, or pursuing some other sedentary occupation" as the most appropriate description of their activities [35], respectively. One study focused on the second trimester of pregnancy and found that prevalence of sedentarism was 18% [30], the other study assessed women on the third trimester of pregnancy finding that 29% were sedentary [35]. Three studies analysed the prevalence of sedentary women, however these 3 studies did not use the term 'sedentary', but used different activity categories defined variously by the authors as: "watching television (for a certain amount of time)", or being "mostly sitting". One study found that 15.3% of the studied women watched television or videos for 5 or more hours per day [37], other study found that 34% viewed television 2 h or more per day [29], and the last one found that 31.9% watched television more than 21 h per week, i.e. about 3 h per day [42]. Additionally 1 of the studies found that 24% of women were "mostly sitting" during usual daily activities [37] (Table 4). Comparison of data was difficult due to different cut-offs to define sedentary behaviour and categorisation of sedentarism.

Change in sedentary behaviour during pregnancy

Among the included studies, 5 aimed to determine whether time spent in sedentary behaviours was stable or changed during gestation [8, 10–12, 37]. Four of these studies examined minutes per day or percentage of day spent in sedentary activities based on objective measures [8, 10–12]. Of these, only 1 found that the percentage of time awake spent in sedentary behaviours significantly increased between week 18 and 35 of gestation [8]. Another study found that women spent a mean of 40 min (standard deviation ±75) less in "very light sitting activities" (activities that spend around 1.3 times the basal metabolic rate) in later gestation than in earlier gestation [38]. The 3 studies which objectively assessed time or percentage of time of monitored time spent in sedentary behaviours, did not find significant differences in time spent in sedentary behaviours between trimesters of gestation [10–12]. When focused on the number of sedentary pregnant women across gestation, more women were sedentary during the third trimester than during the second trimester (18%, $n = 155$; 24.9%, $n = 215$, respectively) [30]. When the time spent between trimesters in TV watching and computer use was compared, no differences were found [37].

Table 3 Time and proportion of time spent in sedentary behaviours

	Studies	N	Mean or median (SD or SE or IQR)
Time spent in SB (objective)			
Time spent in SB (h/day)	Ruifrok 2014 [12]	111	8.6 (SD 2.86)
	Hawkins 2014 [10]	294	9.2 (SE 16.2)[a]
	Loprinzi 2013 [44]	206	7.7 (SE 0.2)[a]
	Hjorth 2012 [9]	304	18.3[a] (IQR16.65–19.6)
	Evenson 2011 [11]	359	7.07 (SE 0.165)[a]
	Di Fabio 2015 [8]	46	12.65 (SD 1.95)[a]
Sitting quietly or very light sitting activities (h/day)	Van Raaij 1990 [38]	18	6.7 (SD1.6)[a]
Light to moderate sitting activities (h/day)	Van Raaij 1990 [38]	18	1.6 (SD1.1)[a]
Sit/lie time (h/day)	Di Fabio 2015 [8]	46	18.2 (IQR17.1–19) w18; 18.3 (IQR17.6–19.4) w35
Time spent in SB (non-objective)			
Television time (h/day)	Padmapriya 2015 [42]	1171	2.4 (SD1.5)[a]
Total sitting time (h/day)	Padmapriya 2015 [42]	1171	8.6 (SD3.3)[a]
Proportion of time spent in SB (objective)			
% of day spent in SB	Hjorth 2012 [9]	304	76.4% (IQR 69.37–81.6[a])
% of wear time spent in SB	Ruifrok 2014 [12]	111	65%
	Evenson 2011 [11]	359	57.1% (SE 0.77)
	Hawkins 2014 [10]	294	64.4% (SE 0.02)[a]
% of time awake in SB	Di Fabio 2015 [8]	46	76% (SD11) w18–78% (SD13) w35
% of day time in sit/lie	Di Fabio 2015 [8]	46	76% (IQR71–79) w18; 76% (IQR73–81) w35

[a] Numbers were calculated as means and converted to the same units

Five studies compared sedentary behaviours between pregnant and non-pregnant women [35, 38, 42, 43, 47]. Four compared from before pregnancy to during pregnancy, and 1 compared pregnant women versus one year postpartum women [38]. Three studies used non-objective methods [35, 42, 43], and 2 objective procedures [38, 47] to assess sedentary behaviours. All found that the time spent in sedentary activities is significantly greater among pregnant than non-pregnant women.

When the number of women that watched television for long periods was compared before and after pregnancy, 1 study observed that the number increased [42], and the other found no change [29].

Additional factors affecting sedentary lifestyles

Some studies considered additional factors which could influence the development of sedentary lifestyles. These factors included: smoking, meeting physical activity recommendations, parity, maternal age, and education level. Time spent in sedentary behaviours was significantly less among women who smoked cigarettes in the past 5 days, compared to those who did not [11]. Time spent in sedentary behaviours at 35 weeks of gestation was significantly less among women meeting physical activity guidelines compared to women who did not [8]. During pregnancy women expecting their first child decreased their sedentary time significantly more than non-

Table 4 Prevalence of sedentarism among pregnant women

Sedentary activity definition	Studies	Assessment method	N	Prevalence
Sedentary	Jiang 2012 [30]	Objective	862	18%
	Hegaard 2011 [35]	Non-objective	4718	29%
Watching TV or videos 5 or more (h/day)	Evenson 2011 [11]	Non-objective	359	15.3%
Watching TV 2 or more (h/day)	Oken 2006 [29]	Non-objective	1581	34%
Watching TV 3 or more (h/day)	Padmapriya 2015 [42]	Non-objective	1171	31.9%
Mostly sitting during day	Evenson 2011 [11]	Non-objective	359	24%

pregnant women without children, as well as first time pregnant women also decreased their sedentary time significantly more than those expecting their second baby as pregnancy advanced [33]. When the changes before and during gestation were compared, women aged 16–19 years, significantly decreased their sedentary activity compared to those aged 20–24 years. Women who had completed college, also significantly decreased their sedentary activity during pregnancy, compared with those with less than a high school education [43].

Interruptions during sedentary time

One study focused on the transitions between sit to stand, using an objective device that evaluates postural allocation [8]. No differences were found in sit/lie and upright time between week 18 and 35 of gestation. However, the number of transitions between sedentary (sit/lie) to upright per day and the number of sit/lie bouts increased significantly from week 18 to week 35 of gestation, whilst the length of sit/lie bout in minutes per day significantly decreased across this gestation window.

Associations between sedentary behaviours and maternal and infant outcomes

Birth and gestation outcomes associated with sedentary behaviours were studied in 14 of the included studies [10, 12, 30–32, 34, 36, 39, 40, 44–47, 49]. Of these, 7 were focused on pregnancy outcomes including gestational weight gain (GWG) and maternal depression [12, 30, 34, 40, 44–46], 5 on metabolic outcomes [10, 36, 44, 47, 49], and 5 on infant outcomes [12, 31, 32, 39, 49].

Associations between sedentary behaviours and pregnancy outcomes (Table 5)

Three studies investigated whether there is an association between sedentary behaviours and gestational weight gain [12, 30, 40]. One study found no association between percentage of time spent in sedentary behaviours with gestational weight gain at 15 weeks of gestation, between 15 and 32–35 weeks of gestation, or with gestational weight gain per week [12]. Likewise, change in percentage of time in sedentary behaviours during 15 to 32–35 weeks of gestation was not associated with total gestational weight gain or with gestational weight gain per week. Another study also observed no significant associations between sedentary activity and inadequate or excessive gestational weight gain, at each stage of pregnancy [40]. However, in another study the 'Active' group (named according to author's categorisation) gained significantly lower maternal weight during the second and third trimesters than the 'sedentary' group (named according to author's categorisation) [30].

Three studies explored the association between pregnancy sedentary behaviours and hypertensive disorders during gestation. Two studies found no association [34, 44], but 1 study found that women who had persistent sedentary work (and were not authorised to move from their work place during working hours), such as sewing operators, developed significantly more gestational

Table 5 Associations between sedentary behaviours and maternal health outcomes

	Author	Participants	Association (Yes/No)
Pregnancy Outcomes			
GWG	Ruifrok 2014 [12]	111	No
	Chasan-Taber 2014 [40]	1276	No
	Jiang 2012 [30]	862	Yes[a] ($p < 0.001$)
Hypertensive disorders	Chasan-Taber 2015 [34]	1240	No
	Loprinzi 2013 [42]	206	No
	Li 2007 [46]	405	Yes[b] ($p < 0.05$)
Depression	Watts 2013 [45]	81	No
Metabolic Outcomes			
Glucose levels	Loprinzi 2013 [44]	206	Trend ($p = 0.06$)
	Hayes 2014 [49]	183	No
Insulin sensitivity	Gradmark 2011 [47]	101	No
GDM	Hayes 2014 [49]	183	No
AGT	Gollenberg 2010 [36]	1006	No
CRP	Loprinzi 2013 [44]	206	Yes[c] ($p < 0.05$)
	Hawkins 2014 [10]	294	Yes[c] ($p < 0.05$)
Blood lipids levels (Total Cholesterol, HDL-cholesterol and triglycerides)	Loprinzi 2013 [44]	206	Yes[d] (LDL $p < 0.05$)
Infant outcomes			
Birth Weight	Ruifrok 2014 [12]	111	No
	Hegaard 2010 [32]	4558	No
	Both 2010 [31]	11759	Yes[e] ($p < 0.05$)
Macrosomia	Reid 2014 [39]	100	Yes[f] ($p < 0.05$)
New-born abdominal circumference	Hayes 2014 [49]	183	Yes[g] ($p < 0.05$)
Gestational length	Ruifrok 2014 [12]	111	No
	Both 2010 [31]	11759	No
Risk of preterm delivery	Both 2010 [31]	11759	No

[a] GWG was higher in the sedentary group compared with the active group, [b] the sedentary group developed more hypertension, [c] Increased time in sedentary behaviours is associated with higher levels of CRP, [d] increased time in sedentary behaviour is associated with higher LDL cholesterol, [e] Increased time in sedentary behaviour is associated with lower birth weight, [f] women delivering macrosomic infants had higher levels of SB, [g] the association between SB and new-born abdominal circumference was inverse at baseline, and positive at 36 weeks

hypertension than women in the control group, whose work was also mostly sedentary, but whom were allowed to move during working time, such as secretaries [46].

No association was found between pregnancy sedentary behaviours and depression [45].

Associations between sedentary behaviours and metabolic outcomes (Table 5)

The relationship between time spent in sedentary behaviours and fasting glucose levels was analysed in 1 study, finding a positive association [44]. On the other hand, sedentary behaviours were not associated with altered insulin sensitivity [47], gestational diabetes mellitus [49], or abnormal glucose tolerance [36]. Two studies found associations between sedentary behaviours and C-reactive protein (CRP) [10, 44]. In 1 study sedentary time and proportion of wear time spent sedentary were positively associated with CRP among women in the second trimester, but this finding was no longer statistically significant in analyses adjusting for confounders [10]. In the other study the positive association between sedentary behaviours and CRP levels remained after adjustment for confounders [44]. A significantly positive association between time spent in sedentary behaviours and higher LDL cholesterol was found in 1 study, but no association was found with any other blood lipid marker [44].

Associations between sedentary behaviours and infant outcomes (Table 5)

Two studies found no association between birth weight and mother's sedentary behaviours during pregnancy [12, 32]. One study found a significant association between lower birthweight with time spent in sedentary lifestyle in each trimester of gestation [31], whilst another found that women who delivered macrosomic infants (birthweight ≥4000 g) spent significantly more time sedentary than women delivering offspring weighing less than 4000 g [39]. The 1 study exploring the correlation between the new born abdominal circumference (as an indicator for abdominal adiposity) with mothers' time spent sedentary found differing results according to gestation. At 16–18 weeks of gestation a significantly inverse association was found between infant abdominal circumference and time spent sedentary, however at 36 weeks of gestation, the relationship became significantly positive [49]. No associations were found between sedentary behaviours and gestational length [12, 31], or risk of preterm delivery [31].

Quality assessment results

Both reviewers agreed that 2 (7.7%) of the studies were of good quality [48, 49], 3 (11.5%) were classified as of poor quality [37, 45, 46], and the rest 21 as intermediate (80.8%).

The 2 studies that were classified as good quality were randomised controlled trials.

Of those classified as poor quality the main reasons were small sample size [45, 46], use of a non-objective appraisal tool to classify women as sedentary [37, 45, 46] and lack of detail about the outcome measures [37, 46].

Discussion

Main findings

There is increasing interest in research in the general population about whether reducing time spent in sedentary behaviours has a beneficial effect on health [50, 51]. Here we systematically reviewed the literature in this field among pregnant women. Our key findings were that pregnant women spend at least half of their time in sedentary activities, which is similar to time reported in children, young people, adults and older adults in the UK [6]. Whether sedentary behaviours impact on pregnancy outcomes was less clear-cut with inconsistencies in the literature.

Our review highlights the considerable heterogeneity in the definitions of sedentary behaviours and the methods used to assess this. Differences in the reported prevalence of sedentary behaviours between studies could be due to the unclear definition of sedentary behaviours, or classification of sedentary. For example, 1 study used a pedometer, an objective method, to classify women as sedentary, considering less than 5000 steps per day as a sedentary lifestyle [30], meanwhile in another study women were considered sedentary if they answered "Reading, watching television, or pursuing some other sedentary occupation", as the most appropriate description of their activities during pregnancy [35]. Many of included studies defined sedentary behaviours as activities expending the same or less than one metabolic equivalent [39, 41], however there is no consensus in how many hours per day spent in sedentary behaviours are sufficient to be categorised as sedentary, making it difficult to determine the prevalence of sedentarism. In addition sedentary behaviours were often assessed retrospectively [32, 35], potentially introducing recall bias.

Studies also differed in the assessment measures to calculate sedentary behaviours making comparisons difficult. This corresponds with what has been exposed regarding sedentary behaviours assessment in other populations [6].

Half of the identified studies considered whether sedentary behaviour in pregnancy impacted on maternal or offspring outcomes. This is an important consideration as interventions based on increasing physical activity among obese pregnant women have had limited impact on pregnancy outcomes [49, 52–55]. One study found that reducing time spent in sedentary activity was associated with decreased gestational weight gain [30]. Two other studies, including a large study of >1000 women found no associations with gestational weight gain [12, 40]. Likewise there were discrepancies in studies examining associations of sedentary behaviours with hypertensive disorders [34, 44, 46]. Notably the 1 study which found a significant association was classified as poor quality, which decreases the reliability of the result [46]. Differences in ethnicity between the study populations may partly explain the discrepant findings with gestational weight gain (1 study developed in Denmark, other included only Latin-American pregnant women, and 1 was developed in China) and hypertensive disorders (1 included only Latin-American women, 1 was developed in the USA and 1 in China). No association was found between depression and sedentary behaviours, however the 1 study focusing on that was classified as poor quality [45]. None of the studies reported associations between sedentary behaviour and glucose metabolism, as assessed by fasting glucose levels [44, 49], insulin sensitivity (measured using an oral glucose tolerance test) [47], gestational diabetes mellitus (GDM) [49] and in a large study of >1000 women glucose tolerance measured during a glucose tolerance test [36]. In contrast, 2 studies found associations between higher CRP levels and increased sedentary behaviour [10, 44], and 1 found an association with blood lipids [44] suggesting there may be subtle beneficial effects on maternal metabolism if time spent sedentary is reduced. Overall, there was some suggestion that sedentary behaviours may impact on size at birth [31, 39, 49], but not timing of delivery [12, 31]. However, the largest study including over 11,000 pregnant women and which reported associations of sedentary behaviour with birthweight but not gestational length or risk of preterm birth, assessed sedentary behaviours during pregnancy using a postal questionnaire using the question "Are/were you mostly sitting?" [31].

Strengths and limitations

The strengths of this review include the systematic and comprehensive review process which was followed in line with PRISMA guidelines. Two researchers independently assessed eligibility of the titles, abstracts and full-text studies, extracted the data and assessed the articles for bias.

A further strength of the review is that many of the studies were of considerable sample size. Eleven studies included samples of over 1000 women [29, 34, 36, 37, 40, 42, 43], including 2 assessing more than 4000 women using validated questionnaires [32, 35]. Nevertheless, larger studies using objective assessments of sedentary behaviour in pregnancy would considerably add to the literature in this field.

There are also some potential limitations. Though we used a robust search strategy developed from other systematic reviews of sedentary behaviour in the general population [2, 56, 57], it is possible that some potentially eligible studies may not have been identified. For example, some studies appraise sedentary behaviours when assessing physical activity, but the titles do not mention the key words we chose to identify sedentary behaviours. We included a search of reference lists of all papers that the full text was read, to identify any further additional papers.

A limitation of the data is that only 2 of the identified studies were trials, all the rest were observational. Of the trials, just 1 used an objective method to assess sedentary behaviours, the other employed a questionnaire. Of the 24 observational studies, only 12 used objective instruments, the other 12 utilised self-reported methods to assess sedentary behaviours. Most of these studies were considered of intermediate quality due to the small sample size, or lack of use of a validated questionnaire or objective measurement. Therefore, the use of objective methods, such as accelerometers, or the combination of movement and physiological (e.g. heart rate) devices should be encouraged if we wish to provide a more clear, realistic, and objective estimate of time spent in sedentary behaviours. Also, the cut-offs used for defining sedentary behaviours as to categorise people as sedentary are not clear and differ between studies, and should be standardised.

Although 3 studies (11.5%) were classified as poor quality one of these [37] did not report any maternal or infant outcomes and so will not have influenced our interpretation of the literature. As noted the findings of the other 2 poor quality rated studies [45, 46] should be interpreted with caution. The rest of the studies were classified at least as intermediate quality, mostly because the designs were less reliable (not randomised controlled trials), most of the sample size were small, some utilised non-objective assessment methods, and/or were not validated, but we are confident that they are representative of the available literature.

Conclusions

The observation that pregnant women spend much of their time in sedentary activities opens new approaches aiming to improve pregnant women's health. However our review has identified important gaps in our understanding in this field. For example only 2 studies considered sleeping time during pregnancy [8, 38] which may be an important consideration when assessing sedentary behaviour due to changing sleep patterns in pregnancy. Further, only 1 study assessed the transitions from sit/lay to stand, or breaks during sedentary time

[8], which may be an important area to target in future interventions studies.

Our review highlights a high prevalence of sedentarism and significant time spent in sedentary behaviours, also that changes in sedentary behaviour may impact on pregnancy outcomes for both mother and child, emphasising this as an area for future mechanistic and intervention studies. However, the heterogeneity in the literature suggests future studies should use robust methodology, preferably with objective measures for quantifying sedentary behaviour.

Additional file

Additional file 1: Database search strategy. (PDF 8 kb)

Abbreviations
CF: Caterina Fazzi; CRP: C-reactive protein; GRADE: Grading of Recommendations Assessment Development and Evaluation; KL: Kathryn Linton; MeSH: Medical subject headings; MOOSE: Meta-analysis of Observational Studies in Epidemiology; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses

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Availability of data and materials
Not applicable.

Authors' contributions
CF conducted all aspects of the review and wrote the manuscript. KL carried out the literature review and approved the manuscript. DS supervised the conduct of the review and wrote the manuscript. JN supervised the conduct of the review and wrote the manuscript. RR carried out the systematic review and wrote the manuscript. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Consent for publication
Not applicable.

Ethics approval and consent to participate
Not applicable as this is a systematic review. We registered our intention to conduct the review with Prospero.

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Appendix 2

Pregnancy Physical Activity Questionnaire

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UMASS

Pregnancy Physical Activity Questionnaire

Instructions:
Please use an ordinary No. 2 pencil. *Fill in the circles completely. The Question will be read by a machine so if you need to change your answer, erase the incorrect mark* ***completely****. If you have comments, please write them on the back of the questionnaire.*

Example: During this trimester, when you are NOT at work, how much time do you usually spend:

E1. **Taking care of an older adult**

If you take care of your mom for 2 hours each day, then your answer should look like this... →

- ○ None
- ○ Less than 1/2 hour per day
- ○ 1/2 to almost 1 hour per day
- ○ 1 to almost 2 hours per day
- ● 2 to almost 3 hours per day
- ○ 3 or more hours per day

It is very important you tell us about yourself honestly. There are no right or wrong answers. We just want to know about the things you are doing during this trimester.

1. Today's Date: ☐☐ / ☐☐ / ☐☐☐☐ (Month / Day / Year)
2. What was the first day of your last period? ☐☐ / ☐☐ / ☐☐☐☐ (Month / Day / Year) ○ I don't know
3. When is your baby due? ☐☐ / ☐☐ / ☐☐☐☐ (Month / Day / Year) ○ I don't know

---

During this trimester, when you are NOT at work, how much time do you usually spend:

4. **Preparing meals (cook, set table, wash dishes)**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 1 hour per day
   - ○ 1 to almost 2 hours per day
   - ○ 2 to almost 3 hours per day
   - ○ 3 or more hours per day

5. **Dressing, bathing, feeding children while you are <u>sitting</u>**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 1 hour per day
   - ○ 1 to almost 2 hours per day
   - ○ 2 to almost 3 hours per day
   - ○ 3 or more hours per day

During this trimester, when you are NOT at work, how much time do you usually spend:

6. **Dressing, bathing, feeding children while you are standing**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 1 hour per day
   - ○ 1 to almost 2 hours per day
   - ○ 2 to almost 3 hours per day
   - ○ 3 or more hours per day

7. **Playing with children while you are sitting or standing**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 1 hour per day
   - ○ 1 to almost 2 hours per day
   - ○ 2 to almost 3 hours per day
   - ○ 3 or more hours per day

8. **Playing with children while you are walking or running**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 1 hour per day
   - ○ 1 to almost 2 hours per day
   - ○ 2 to almost 3 hours per day
   - ○ 3 or more hours per day

9. **Carrying children**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 1 hour per day
   - ○ 1 to almost 2 hours per day
   - ○ 2 to almost 3 hours per day
   - ○ 3 or more hours per day

10. **Taking care of an older adult**
    - ○ None
    - ○ Less than 1/2 hour per day
    - ○ 1/2 to almost 1 hour per day
    - ○ 1 to almost 2 hours per day
    - ○ 2 to almost 3 hours per day
    - ○ 3 or more hours per day

11. **Sitting and using a computer or writing, while not at work**
    - ○ None
    - ○ Less than 1/2 hour per day
    - ○ 1/2 to almost 1 hour per day
    - ○ 1 to almost 2 hours per day
    - ○ 2 to almost 3 hours per day
    - ○ 3 or more hours per day

12. **Watching TV or a video**
    - ○ None
    - ○ Less than 1/2 hour per day
    - ○ 1/2 to almost 2 hours per day
    - ○ 2 to almost 4 hours per day
    - ○ 4 to almost 6 hours per day
    - ○ 6 or more hours per day

13. **Sitting and reading, talking, or on the phone, while not at work**
    - ○ None
    - ○ Less than 1/2 hour per day
    - ○ 1/2 to almost 2 hours per day
    - ○ 2 to almost 4 hours per day
    - ○ 4 to almost 6 hours per day
    - ○ 6 or more hours per day

14. **Playing with pets**
    - ○ None
    - ○ Less than 1/2 hour per day
    - ○ 1/2 to almost 1 hour per day
    - ○ 1 to almost 2 hours per day
    - ○ 2 to almost 3 hours per day
    - ○ 3 or more hours per day

15. **Light cleaning (make beds, laundry, iron, put things away)**
    - ○ None
    - ○ Less than 1/2 hour per day
    - ○ 1/2 to almost 1 hour per day
    - ○ 1 to almost 2 hours per day
    - ○ 2 to almost 3 hours per day
    - ○ 3 or more hours per day

16. **Shopping (for food, clothes, or other items)**
    - ○ None
    - ○ Less than 1/2 hour per day
    - ○ 1/2 to almost 1 hour per day
    - ○ 1 to almost 2 hours per day
    - ○ 2 to almost 3 hours per day
    - ○ 3 or more hours per day

9364

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During this trimester, when you are NOT at work, how much time do you usually spend:

17. **Heavier cleaning (vacuum, mop, sweep, wash windows)**

- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

18. **Mowing lawn while on a riding mower**
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

19. **Mowing lawn using a walking mower, raking, gardening**
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

Going Places...

During this trimester, how much time do you usually spend:

20. **Walking slowly to go places (such as to the bus, work, visiting)**
Not for fun or exercise
- ○ None
- ○ Less than 1/2 hour per day
- ○ 1/2 to almost 1 hour per day
- ○ 1 to almost 2 hours per day
- ○ 2 to almost 3 hours per day
- ○ 3 or more hours per day

21. **Walking quickly to go places (such as to the bus, work, or school)**
Not for fun or exercise
- ○ None
- ○ Less than 1/2 hour per day
- ○ 1/2 to almost 1 hour per day
- ○ 1 to almost 2 hours per day
- ○ 2 to almost 3 hours per day
- ○ 3 or more hours per day

22. **Driving or riding in a car or bus**
- ○ None
- ○ Less than 1/2 hour per day
- ○ 1/2 to almost 1 hour per day
- ○ 1 to almost 2 hours per day
- ○ 2 to almost 3 hours per day
- ○ 3 or more hours per day

For Fun or Exercise...

During this trimester, how much time do you usually spend:

23. **Walking slowly for fun or exercise**
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

24. **Walking more quickly for fun or exercise**
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

25. **Walking quickly up hills for fun or exercise**
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

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UMASS

During this trimester, how much time do you usually spend:

26. **Jogging**
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

27. **Prenatal exercise class**
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

28. **Swimming**
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

29. **Dancing**
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

Doing other things for fun or exercise? Please tell us what they are.

30. ______________________ Name of Activity
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

31. ______________________ Name of Activity
- ○ None
- ○ Less than 1/2 hour per week
- ○ 1/2 to almost 1 hour per week
- ○ 1 to almost 2 hours per week
- ○ 2 to almost 3 hours per week
- ○ 3 or more hours per week

Please fill out the next section if you work for wages, as a volunteer, or if you are a student. If you are a homemaker, out of work, or unable to work, you do not need to complete this last section.

At Work...

During this trimester, how much time do you usually spend:

32. **Sitting at working or in class**

- ○ None
- ○ Less than 1/2 hours per day
- ○ 1/2 to almost 2 hours per day
- ○ 2 to almost 4 hours per day
- ○ 4 to almost 6 hours per day
- ○ 6 or more hours per day

33. **Standing or slowly walking at work while carrying things (heavier than a 1 gallon milk jug)**
- ○ None
- ○ Less than 1/2 hour per day
- ○ 1/2 to almost 2 hours per day
- ○ 2 to almost 4 hours per day
- ○ 4 to almost 6 hours per day
- ○ 6 or more hours per day

34. **Standing or <u>slowly</u> walking at work <u>not</u> carrying anything**
- ○ None
- ○ Less than 1/2 hours per day
- ○ 1/2 to almost 2 hours per day
- ○ 2 to almost 4 hours per day
- ○ 4 to almost 6 hours per day
- ○ 6 or more hours per day

35. **Walking <u>quickly</u> at work while <u>carrying</u> things (heavier than a 1 gallon milk jug)**
- ○ None
- ○ Less than 1/2 hour per day
- ○ 1/2 to almost 2 hours per day
- ○ 2 to almost 4 hours per day
- ○ 4 to almost 6 hours per day
- ○ 6 or more hours per day

36. **Walking <u>quickly</u> at work <u>not</u> carrying anything**
- ○ None
- ○ Less than 1/2 hour per day
- ○ 1/2 to almost 2 hours per day
- ○ 2 to almost 4 hours per day
- ○ 4 to almost 6 hours per day
- ○ 6 or more hours per day

Thank You

Appendix 3

Questionnaire: Physical Activity Information in Pregnancy

Tommy's

QUESTIONNAIRE: PHYSICAL ACTIVITY INFORMATION IN PREGNANCY

We are evaluating the lifestyle information you receive during pregnancy and looking at ways that we can improve the information we give you. More specifically we want to know more about physical activity and also sedentary behaviours, which refer to all those activities that require very low energy, such as sitting or lying.

Many thanks for taking the time to complete this questionnaire.

NAME:.. Date..

1.Have you received any information about physical activity in pregnancy during your pregnancy? Yes/No

If yes -

Who gave you the information?

Did you find the information useful?

Was there anything that you felt was missing from the information?

2. Before reading this questionnaire, had you heard about sedentary behaviours or sedentary lifestyles? Yes/No

If yes -

Where did you hear about it? ____________________

What did you know about sedentary behaviours? ____________________

____

3. During pregnancy, have you ever received any information about altering sedentary behaviours such as reducing time spent sitting? Yes/No

If yes -

What was the information you received? ____________________

____

Who gave you that information? ____________________

Recent studies suggest that spending too much time in sedentary behaviours may affect the health and wellbeing of mothers and babies during pregnancy. Therefore, we would like to help pregnant women spend less sedentary time during pregnancy. We are therefore investigating what type of information would be useful for pregnant women to encourage them to be less sedentary.

5. Would you be interested in knowing about how to change the time you spend in sedentary activities? Yes/No

6. Would you prefer to receive this information by leaflet or just to be told about it during your consultation? ____________________

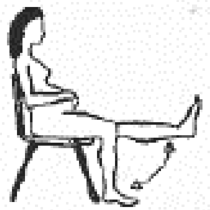
7. Would you wear a device (such as a pedometer/accelerometer) to assess your energy expenditure for three days? Yes/No

8. Would you prefer to wear this device at your hips or on the wrist? ____________________

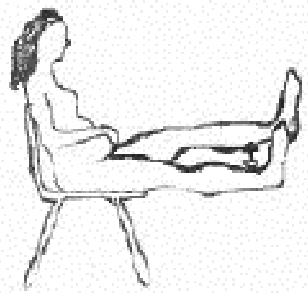
9. If you were offered the following as suggestions to alter the time you are spending in sedentary activities, which would you think would be achievable?

For example, while sitting and watching TV:

- Stretch and bend your legs continuously for a few minutes. Yes/No



- Hold your legs in the air for a few seconds opening and closing them for a few minutes. Yes/No



Meanwhile lying on your side:

- Hold one of your legs in the air opening and closing them repeatedly as they were scissors. Yes/No

10. Do you have any other ideas about what activities would be useful for you to change your time spent in sedentary activities?

Appendix 4

Exercise Intervention Feedback Form

Version 1.0, 1st March 2017

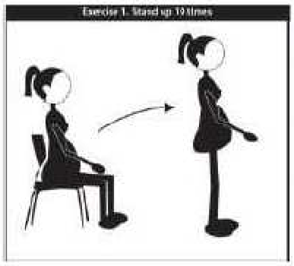
Tommy's THE UNIVERSITY of EDINBURGH MRC Centre for Reproductive Health

METABOLIC ANTENATAL CLINIC INTERVIEW

Name ______________________________

Date ________________

Exercise 1.



Repetitions_______________

Intensity (Borg 1-10) _______

Comfortable? Yes □ or No □

Comments ______________________________

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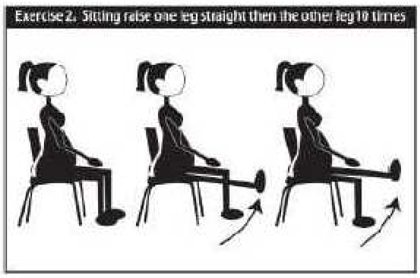
Exercise 2.

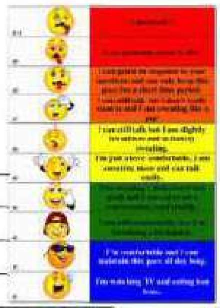


Repetitions_______________

Intensity (Borg 1-10) ______

Comfortable? Yes □ or No □

Comments ______________________________



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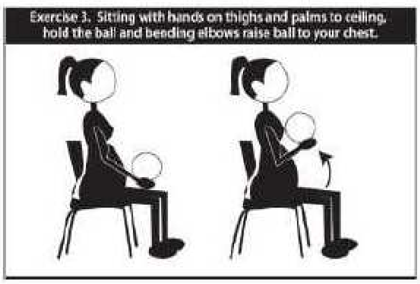
Exercise 3.



Repetitions_______________

Intensity (Borg 1-10) ______

Comfortable? Yes □ or No □

Comments ______________________________

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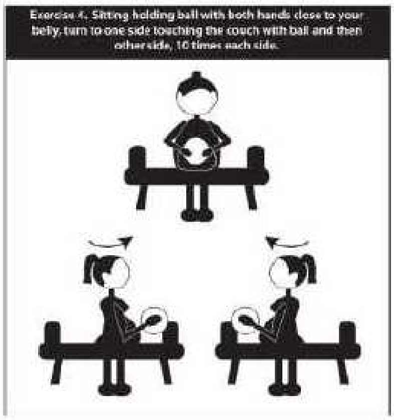
Exercise 4.



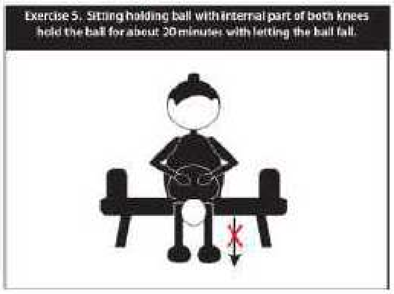
Repetitions_______________

Intensity (Borg 1-10) _______

Comfortable? Yes □ or No □

Comments ____

Exercise 5.



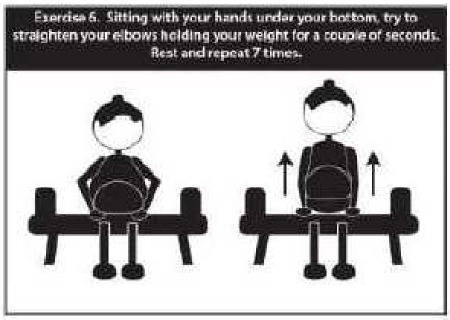
Time (seconds) _______________

Intensity (Borg 1-10) _______

Comfortable? Yes □ or No □

Comments ____

Exercise 6.

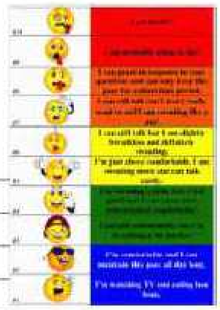


Repetitions _______________

Intensity (Borg 1-10) _______

Comfortable? Yes □ or No □

Comments ____



Version 2.0, 20th April 2017

Tommy's

THE UNIVERSITY of EDINBURGH

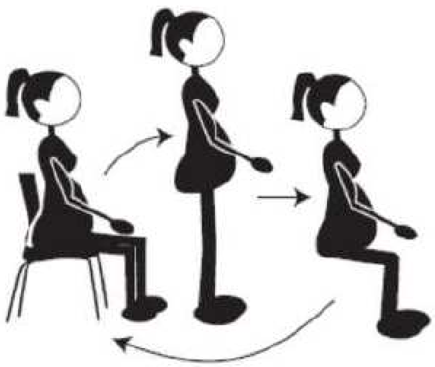
MRC Centre for Reproductive Health

METABOLIC ANTENATAL CLINIC INTERVIEW

Name ______________________________

Date ________________

Exercise 1. From sitting stand up and before sitting back squad for 10-20 seconds, and sit. Repeat 10 times. 2 sets.



Time (seconds) ________ Repetitions _________

Intensity (Borg 1-10) _______

Comfortable? Yes □ or No □

Comments ______________________________

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Exercise 2. In sitting position, straight both legs, and hold the ball for 20-30 seconds. Repeat 10 times. 2 sets.

Time (seconds) _______________

Intensity (Borg 1-10) ______

Comfortable? Yes □ or No □

Comments ______________________________

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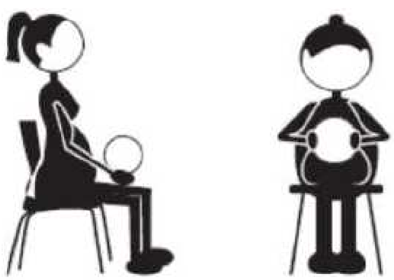
Exercise 3. In sitting, with both arms in horizontal position and your elbows bended, hold and squeeze the ball for 5-10 seconds, then release for 2 seconds without moving the arms, and squeeze immediately again. Repeat 10 times. 2 sets.



Time (seconds) _______________

Intensity (Borg 1-10) ______

Comfortable? Yes □ or No □

Comments ______________________________

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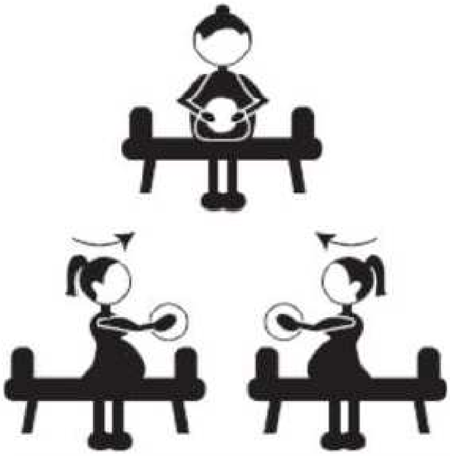
Exercise 4. In sitting position, with your elbows in extension, hold the ball with both hands, turn to one side then to the other side. Repeat 10 times (both sides id one repetition). 2 sets.



Repetitions ________________

Intensity (Borg 1-10) _______

Comfortable? Yes □ or No □

Comments ___________________________________

Exercise 5. In sitting position, with the internal part of both knees hold the ball, squeeze for 5-10 seconds and release 2 seconds. Repeat 10 times. 2 sets.

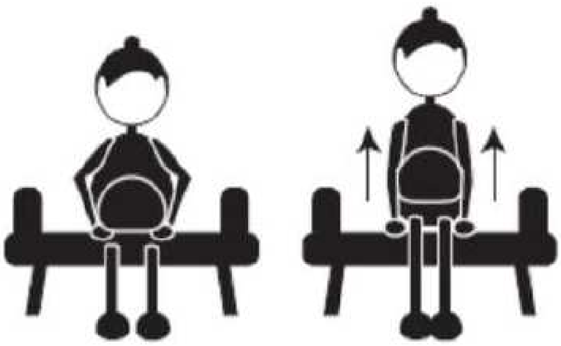
Time (seconds) ________________

Intensity (Borg 1-10) _______

Comfortable? Yes □ or No □

Comments ___________________________________

Exercise 6. In sitting position, with your hands under the bottom, try to straight the elbows holding your weight for 10-20 seconds and release 5 seconds. Repeat, 10 times. 2 sets.



Time (seconds) ________________

Intensity (Borg 1-10) _______

Comfortable? Yes □ or No □

Comments ___________________________________

Appendix 5

OPALS Feasibility Questionnaire

Tommy's
[Let's talk baby]

Participant number:

OPTIONS IN PREGNANCY TO INCREASE ACTIVELY SITTING (OPALS) FEASIBILITY STUDY

OPALS Study

Dear participant, thank you so much for taken part in the OPALS Feasibility Study. To know how to improve the intervention, we need to ask you some questions regarding your experience in the study. Thanks for your help!

Feasibility Questionnaire

1. How many weeks have you taken part in the OPALS study? ________________.

2. Do you have children? Yes ☐ No ☐ How many? _______.

3. For how long have you been practicing the exercise plan? _____________________.

4. On average how many times a week did you perform the exercises? _________.

5. In general, did you do the exercise plan once a day or more?

   Once ☐ More than once ☐

6. Do you believe that doing the exercises 5 times a week is too much?

   Yes ☐ No ☐

7. On average, how many times a week do you think is the best option to do the exercise plan? ________________________.

8. Was it enjoyable to perform the exercises? Yes ☐ No ☐

9. Will you keep on doing the exercises after 12 weeks? Yes ☐ No ☐

10. Do you think it was easy to participate in the study and accomplish the instructions?

    Yes ☐ No ☐

11. What was the most difficult thing to do? ________________________.

    Why? ____.

12. Do you think something was missing?

    Yes ☐ No ☐ If 'yes' -What? ______________________________.

13. Do you think that your body performance improved after a while of practicing the exercises? Yes ☐ No ☐ Not sure ☐

14. Did the exercises make you feel better? Yes ☐ No ☐ Not sure ☐

15. Did you find the Activity Diary helpful? Yes ☐ No ☐ Not sure ☐

Appendix 6

Activity behaviors in lean and morbidly obese pregnant women

Accepted: 8 May 2018
DOI: 10.1111/sms.13219

ORIGINAL ARTICLE

WILEY

Activity behaviors in lean and morbidly obese pregnant women

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Funding information
Comisión Nacional de Investigación Científica y Tecnológica; Tommy's and the Medical Research Council, Grant/Award Number: MR/N022556/1; Universidad Metropolitana de Ciencias de la Educacion

Interventions to increase physical activity in pregnancy are challenging for morbidly obese women. Targeting sedentary behaviors may be a suitable alternative to increase energy expenditure. We aimed to determine total energy expenditure, and energy expended in sedentary activities in morbidly obese and lean pregnant women. We administered the Pregnancy Physical Activity Questionnaire (nonobjective) and the Actical accelerometer (objective) to morbidly obese (BMI $\geq$ 40 kg/m²) and lean (BMI $\leq$ 25 Kg/m²) pregnant women recruited in early (<24 weeks), and late ($\geq$24 weeks) gestation. Data are mean (SD). Morbidly obese pregnant women reported expending significantly more energy per day in early (n = 140 vs 109; 3198.4 (1847.1) vs 1972.3 (10284.8) Kcal/d, $P < .0001$) and late (n = 104 vs 64; 3078.2 (1356.5) vs 1947.5 (652.0) Kcal/d, $P < .0001$) pregnancy, and expended significantly more energy in sedentary activities, in early (816.1 (423.5) vs 540.1 (244.9) Kcal/d, $P < .0001$) and late (881.6 (455.4) vs 581.1 (248.5) Kcal/d, $P < .0001$) pregnancy, than lean pregnant women. No differences were observed in the proportion of energy expended sedentary between lean and morbidly obese pregnant women. The greater total energy expenditure in morbidly obese pregnant women was corroborated by Actical accelerometer in early (n = 14 per group, obese 1167.7 (313.6) Kcal; lean 781.1 (210.1) Kcal, $P < .05$), and in late (n = 14 per group, obese 1223.6 (351.5) Kcal; lean 893.7 (175.9) Kcal, $P < .05$) pregnancy. In conclusion, nonobjective and objective measures showed morbidly obese pregnant women expended more energy per day than lean pregnant. Further studies are needed to determine whether sedentary behaviors are a suitable target for intervention in morbidly obese pregnancy.

KEYWORDS
energy expenditure, lean, morbidly obese, pregnancy

1 | BACKGROUND

Among women of reproductive age, obesity (body mass index BMI ≥ 30 kg/m^2) levels have increased in the last decades.[1-4] Recent estimates indicate 22% of pregnant women are obese,[5] while around 2% are severely obese (BMI ≥ 40 kg/m^2).[6]

Obesity in pregnancy is associated with adverse outcomes for mother and offspring.[7,8] Interventions to increase energy expenditure are an option to control weight and gestational weight gain, but these are challenging to implement in morbidly obese pregnant women.[9] Indeed previous studies have shown that levels of physical activity are very low among pregnant women,[10] particularly among those that are overweight/obese compared with normal weight.[11] Overweight individuals expend considerably more calories than normal weight individuals doing the same exercise.[12]

Obese pregnant women need more energy to move and have a higher metabolic cost than lean pregnant women, so the work of breathing and moving takes a greater effort, and peripheral motor efficiency is decreased.[13] Studies comparing physical activity between obese and normal weight pregnant women are very scarce,[11] and the majority of interventions based on increasing physical activity levels in obese pregnant women have been largely unsuccessful in preventing adverse pregnancy outcomes.[14-16] Targeting a reduction in sedentary behaviors (ie, activities that expend very low energy, such as sitting or lying or reclining), may be a realistic alternative.[17]

Epidemiological studies show that in the general adult population around 55%-60% of time awake, is spent sedentary.[18,19] In a systematic review, we showed that pregnant women spend more than 50% of their time sedentary.[20] A handful of studies suggest increased time in sedentary behaviors during pregnancy is associated with adverse maternal and offspring outcomes. These include higher maternal levels of LDL cholesterol,[21] C-reactive protein,[21] and gestational diabetes,[22] for the mother, and higher new born abdominal circumference,[23] and risk of macrosomia (birthweight>4000 g),[24] for the offspring.

As little is known about sedentary behaviors in morbidly obese pregnant women, we aimed to determine total energy expenditure, and energy expended in sedentary activities in morbidly obese and lean pregnant women using two validated methods, objective (Actical accelerometer) and nonobjective (PPAQ). We hypothesized that morbidly obese pregnant women would expend less energy in total activities, but proportionally more time in sedentary activities than lean pregnant women.

2 | METHODS

Subjects were morbidly obese (BMI ≥ 40 kg/m²) women with a singleton pregnancy attending the Antenatal Metabolic Clinic at the Royal Infirmary of Edinburgh, UK, and lean (BMI ≤ 25 kg/m²) pregnant women recruited from community antenatal clinics who were participating in a larger study examining the consequences of morbidly obese

TABLE 1 Characteristics of obese and lean participants who completed the PPAQ in early and late pregnancy

	Early			Late		
Characteristic	Lean (n = 109) Mean (SD) or n (%)	M. Obese (n = 140) Mean (SD) or n (%)	*P*-value	Lean (n = 64) Mean (SD) or n (%)	M. Obese (n = 104) Mean (SD) or n (%)	*P*-value
BMI (Kg/m²)	22.8 (2.7)	44.2 (4.5)	<.001	22.8 (1.6)	44.1 (5.0)	<.001
Maternal age (years)	33.06 (4.55)	30.73 (5.40)	<.001	33.61 (4.45)	31.50 (5.26)	<.05
Parity						
0	68 (62.4)	64 (46)	<.01	41 (64.1)	43 (41)	<.01
1	29 (26.6)	41 (29.5)		16 (25)	38 (36.2)	
2	12 (11)	31 (39)		7 (10.9)	20 (19)	
3	0 (0)	2 (1.4)		0 (0)	2 (1.9)	
4	0 (0)	0 (0)		0 (0)	0 (0)	
5	0 (0)	0 (0)		0 (0)	2 (1.9)	
Ethnicity						
Caucasian	97 (89)	124 (89.2)	>.05	54 (84.4)	84 (81)	>.05
Other	0 (0)	4 (2.9)		0 (0)	3 (2.9)	
Deprivation Category						
Low	28 (25.9)	11 (8.0)	<.001	15 (24.6)	12 (11.7)	<.01
Middle	79 (73.1)	103 (75.7)		46 (75.4)	79 (76.7)	
High	1 (0.9)	22 (16.2)		34 (0)	12 (11.7)	
Birth weight (g)	3513 (541)	3574 (558)	>.05	3584 (512)	3511 (595)	>.05
Gestational age at delivery (week)	40.34 (1.34)	39.79 (1.50)	<.005	40.50 (1.38)	39.68 (1.42)	<.001
Weight gain (kg)	10.16 (3.64)	5.87 (5.03)	<.001	10.41 (4.05)	5.59 (5.53)	<.001

Data are mean (SD) or n (%). Weight gain was calculated as Weight week 36—weight weight at baseline.
Deprivation Category is based on postcodes.

pregnancy. Details of the overall cohort have been previously described.[25,26]

Ethical approval was obtained from the Lothian NHS Research Ethics Committee, and all subjects gave informed written consent (REC reference number 08/S1101/39).

In this cross-sectional study, women were asked to complete the Pregnancy Physical Activity Questionnaire (PPAQ) in early (<24 weeks' gestation) and late (>24 weeks' gestation) pregnancy. The PPAQ is designed specifically for pregnant women to assess the energy expended in activities of different intensities. It contains 36 questions and was validated against the Actigraph accelerometer (Manufacturing Technology, Inc.) in pregnant women in 2004.[27] Results on energy expenditure are given in metabolic equivalents[28] per day and as total activity plus four different activity levels (sedentary, light, moderate, and vigorous). Additionally, energy expenditure is given separately in three types of activities (house activities including caring, occupational, and sports or exercise). To show the data in kilocalories per day, we calculated the resting metabolic rate (RMR) using the Mifflin and St. Jeor equation,[29] which has been tested as the best equation to estimate resting energy expenditure in obese and non-obese adults.[30,31]

Energy expenditure was also assessed in early and late pregnancies, in a subset of women (n = 14 per group) using the *Actical* accelerometer (Mini Mitter Company, Inc., USA), which gives data on Active Energy Expenditure in kilocalories per minute a day, and has been validated for use in healthy adult populations.[32] Sedentary activity was classified as time spent performing activities that register less than 100 counts per minute.[33] Women wore the device on their nondominant wrist, for 2 weekdays and 1 weekend day, for 24 hours each day (including sleeping time), and were told to remove the Actical only for bathing, or during water sports activities.

2.1 | Statistical analyses

Data distribution was tested using the Shapiro-Wilk normality test. Continuous variables including time spent in sedentary behaviors, and relative total daily energy expenditure, were compared between morbidly obese and lean pregnant women using *T* tests or ANOVA for normally distributed variables and Mann-Whitney U test for data that were not normally distributed. We compared the proportions of energy expended in the different daily activities between groups using ANOVA or Mann-Whitney as appropriate. Regression analyses were used to adjust for potential confounders when analyzing the PPAQ. In particular we adjusted for parity and socioeconomic status as these have been reported to influence activity levels in other studies[34] and also differed in our sample (Tables S2 and S3). Differences were accepted as

TABLE 2 PPAQ comparisons in total and sedentary energy expenditure between lean and morbidly obese pregnant women in early and late stage

	Early			Late		
	Mean (SD)			Mean (SD)		
	Lean (n = 109)	M. Obese (n = 140)	β (95% CI)[a]	Lean (n = 64)	M. Obese (n = 104)	β (95% CI)[a]
Total EE (Kcal/d)	1972.29 (1028.85)	3198.37 (1847.05)	0.33** (575.73-1390.80)	1947.54 (652.03)	3078.23 (1356.46)	0.43** (699.87-1631.39)
Sedentary Activity EE (Kcal/d)	590.13 (244.90)	816.07 (423.51)	0.37** (180.08-397.11)	581.11 (248.51)	881.65 (455.38)	0.34** (110.69-360.39)

β is the standardised coefficient.

**Significant at $P < .001$.

[a]Adjusted for Maternal Age, Parity, Deprivation Category, and Ethnicity.

significant at $P < .05$. Data were analyzed using IBM SPSS Statistics 19.0 software.

3 | RESULTS

The PPAQ was completed by 109 lean and 140 morbidly obese women in early pregnancy (<24 weeks, range 12-23 weeks), and 64 lean and 104 morbidly obese women in late pregnancy (≥24 weeks, range 24-36 weeks).

Table 1 shows the characteristics of participants who completed the PPAQ. Morbidly obese pregnant women had higher BMI, parity, were of lower deprivation category status, were younger, delivered earlier, and gained significantly less weight than lean pregnant women.

Demographics of the women (n = 14 lean early; 14 lean late; n = 14 morbidly obese early; 14 morbidly obese late) who wore the accelerometer were similar to the full cohort (Table S1).

3.1 | Total energy expenditure and sedentary energy expenditure in morbidly obese and lean pregnant women

When comparing reported energy expenditure using the PPAQ between morbidly obese and lean pregnant women, morbidly obese expended significantly more energy per day as total expenditure, and in sedentary activities in both early and late pregnancies, as shown in Table 2. These differences remained significant in regression analyses adjusting for maternal age, parity, deprivation status, and ethnicity.

Objective measurements of energy expenditure using the Actical confirmed that morbidly obese pregnant women expended significantly more energy than lean pregnant women in early and late pregnancies despite the observation that in both stages of pregnancy morbidly obese pregnant women performed significantly fewer activity counts than lean pregnant women (Table 3).

3.2 | Proportions of total energy expenditure in different intensity activities

Proportions of energy expended in different intensities of activity are shown in Figure 1A,B. In early and late pregnancies, morbidly obese pregnant women expended significantly more energy in light intensity and significantly less energy in vigorous intensity activities than lean pregnant women. Differences in the proportion of time spent in vigorous activities remained significant after the regression analysis, controlling for maternal age, parity, deprivation status, and ethnicity. Differences in the proportion of time in light intensity activities did not remain significant in adjusted analyses. No differences were observed between lean and morbidly obese pregnant women in the proportion of time spent in moderate or sedentary intensity activities.

4 | DISCUSSION

Our findings demonstrate that morbidly obese pregnant women expend more energy in all physical activities other than vigorous activities than lean pregnant women. This is despite the observation that morbidly obese pregnant women have fewer objectively measured activity "counts" than lean pregnant women. Further, though both groups spent a similar time in sedentary activities, morbidly obese pregnant women expended more energy when sedentary than lean pregnant women.

Our observation that morbidly obese pregnant women expended significantly less energy in vigorous activities than lean pregnant women corresponds to other studies showing that this domain of physical activity volume is lower among pregnant women,[10] but even lower among overweight or obese pregnant women.[11] However, we had anticipated that morbidly obese women would spend proportionally more time in sedentary activities than lean women, but objective measures showed time spent sedentary was similar in both groups. The obese group also expended significantly more

TABLE 3 Actical comparisons in counts, total energy expenditure, and sedentary time between lean and morbidly obese pregnant women in early and late stage

	Early Mean (SD)			Late Mean (SD)		
	Lean (n = 14)	M. Obese (n = 14)	Sig	Lean (n = 14)	M. Obese (n = 14)	Sig
Sedentary time (min/d)	762.40 (104.68)	799.33 (101.80)	$P > .05$	740.70 (89.89)	774.15 (124.70)	$P > .05$
Total Activity Counts[a] (per day)	360 160.91 (131 302.13)	268 683.36 (83 567.16	$P < .05$	357 561.03 (94 799.09)	266 820.25 (97 640.51)	$P < .05$
Total EE (Kcal/d)	781.06 (210.15)	1167.69 (313.56)	$P < .01$	893.72 (175.88)	1223.64 (351.47)	$P < .05$

[a]Counts are markers of movement.

total energy daily than lean pregnant women in sedentary activities, consistent with their greater basal metabolic rate.[30] Though morbidly obese pregnant women expended significantly more total energy than lean pregnant women, they registered significantly fewer activity counts than lean women using the Actical accelerometer. Counts assessed by Actical are an indication of movement in relation to different planes, gravitational forces, magnitude, and duration of the sensed acceleration, but not linked to personal characteristics such as gender, age, or body weight.[33] Thus, interventions designed to increase overall movement, many of which could be performed while sedentary, ie, sitting, lying, or reclining, may still be a suitable target for morbidly obese pregnant women. Our observations were similar in early and late pregnancies suggesting any intervention should be started in early pregnancy.

Strength of the study is that we used two different methods to assess energy expenditure and sedentary behaviors, including the PPAQ questionnaire, which has been validated in pregnancy, and an objective device. Due to the detailed characterization of the women, we were able to adjust for potential confounding factors including parity and socioeconomic status which were associated with differences in energy expenditure in our sample, as has been reported by others.[34] Findings remained significant after adjustment for these confounders. Limitations include the

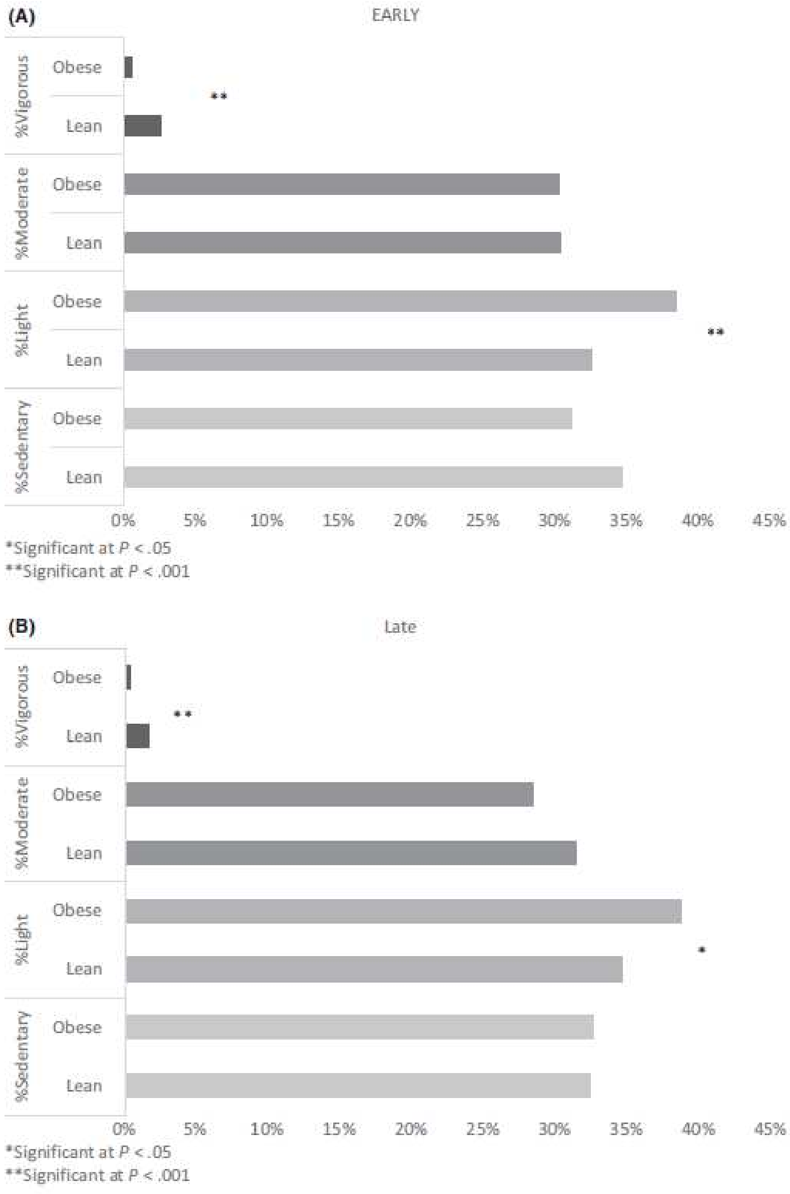

FIGURE 1 A, Percentage of self-reported Energy Expenditure per Activity Intensity in early pregnancy. *Significant at $P < .05$, **Significant at $P < .001$. B, Percentage of self-reported Energy Expenditure per Activity Intensity in late pregnancy. *Significant at $P < .05$, **Significant at $P < .001$

risk of recall bias and potential for lack of reliability of the PPAQ, since subjects might be dishonest or inaccurate in their responses. We also acknowledge the small sample size used with the Actical accelerometer limits interpretation of results. While subjects wore the accelerometer for the recommended time of the manufacturer, we acknowledge this was for a relatively short time. Despite this, the Actical findings for energy expenditure were consistent with the PPAQ outcomes. A further strength is the focus on morbidly obese pregnant women, who may be unable to participate in interventions designed for less severely obese women,[15,35] and have also been identified to have specific barriers to participation in physical activity interventions.[36] We acknowledge that time spent sleeping, which may impact on the time spent sedentary, was not specifically assessed in our study, but we are not aware that sleep duration differs between morbidly obese and lean pregnant women.[37]

Though we used two validated measures to assess physical activity in pregnancy, neither was specifically designed to understand sedentary activities in pregnancy. A recent systematic review highlighted the heterogeneity in assessment of sedentary activity[20] with measures ranging from 7 to 18 hours per day.

4.1 | Perspective

A better understanding of sedentary activity is needed for the design of effective interventions to help to reduce the adverse effects of obesity on pregnancy, especially as obesity prevalence is growing among fertile women,[38] and that there are risks associated with obesity during pregnancy, for mothers and offspring. We have shown that morbidly obese pregnant women expend significantly more energy than lean pregnant women, but they also expend significantly more energy on sedentary activities. These findings suggest that energy expenditure might not be the key factor to obesity, but energy intake might be. Nevertheless, sports and physical activity interventions may play a role as preventive health factors contributing to better and effective alternatives to reduce those risks associated with obesity during pregnancy, and to reduce time spent sedentary.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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Appendix 7

OPALS Study Activity Diary

OPALS FEASIBILITY STUDY

(Options in pregnancy to increase actively sitting)

OPALS Study

Exercise Strategy
ACTIVITY DIARY

INSTRUCTIONS

Thank you very much for taking part in the OPALS Study, we hope you will enjoy the experience of doing the exercises, and we believe you will feel healthier and happier.

This Activity Diary should be completed every day after you have done the exercises. We would like you to do the exercises for at least 12 weeks, repeating them between 3 to 5 times each week. You can do the exercises any time during the day or evening.

How to do the exercises?

You have been provided with a sheet (**Exercise Strategy Guideline**) which explains each exercise, please refer to this as a reminder.

How to complete the diary?

Complete each week of the activity diary entering information on the day you did the exercises. There may be days that are empty, if you do not do the exercises on that day.

Starting date: enter the date which is the Monday of the week you are doing the exercises.

Repetitions: write the number of repetitions you did of the exercises on that day in the space provided; remember to follow the sheet (Exercise Strategy Guideline) where the recommended number of repetitions are explained.

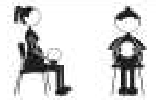
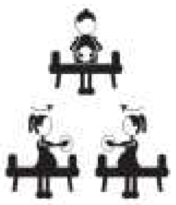
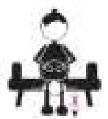
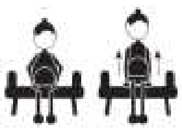
Time: there are only 3 exercises where you have to write time, which refer to the length of time you squeezed the ball (exercises 3 and 5), or held your arms straight continuously (exercise 6). Follow the Exercise Strategy Guideline recommendations.

Sets. Sets are the number of times that you do the sequence of exercises. For instance with exercise **1**, sets are the times you do 10 squats, so if you did 10 squats twice you did 2 sets of 10 repetitions. You should always rest and recover between sets. Do not forget to follow the Exercise Strategy Guideline.

Comments: write any information you would like to tell us about your experience of doing the exercises.

If you have any question or would like some help with doing the exercises, or completing the diary, please call Caterina Fazzi at 01312426614.

Thanks again and let's be more active!!!

Starting date: ___/___/_______		WEEK 1 Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Exercise 2		Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Exercise 4		Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Exercise 5		Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Exercise 6		Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Comments:				

WEEK 1 Thursday	Friday	Saturday	Sunday
Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
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Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
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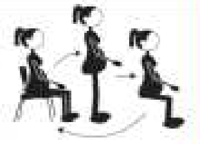
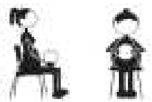
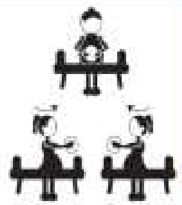
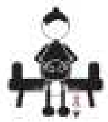
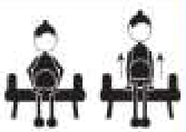
Starting date: ___/___/______		WEEK 2		
		Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
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WEEK 2			
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Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
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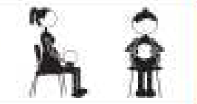
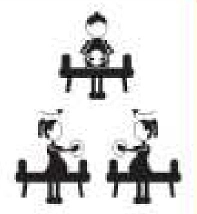
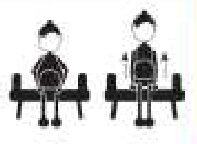
Comments:			

		WEEK 3		
Starting date: ___/____/________		Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______

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WEEK 3			
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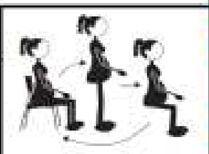
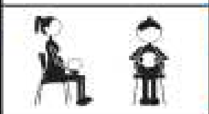
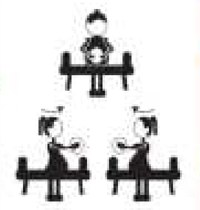
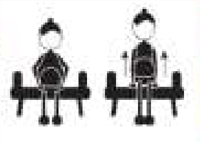
Starting date: ___/___/______		WEEK 4 Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
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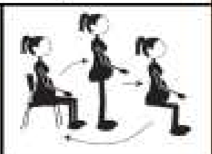
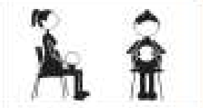
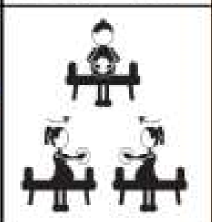
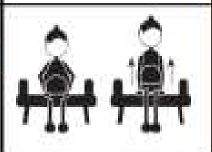
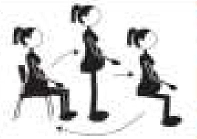
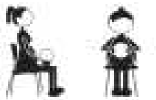
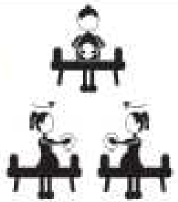
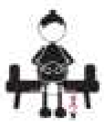
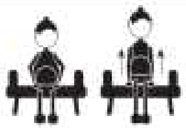
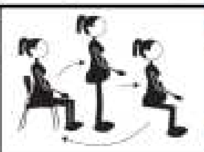
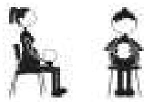
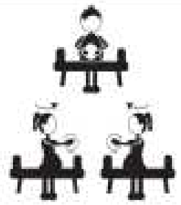
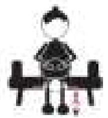
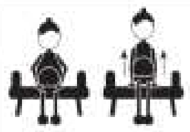
WEEK 4 Thursday	Friday	Saturday	Sunday
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Comments:			

Starting date: ___/___/_______		WEEK 5 Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Exercise 2		Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Exercise 4		Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Exercise 5		Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Exercise 6		Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Comments:				

WEEK 5 Thursday	Friday	Saturday	Sunday
Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Comments:			

		WEEK 6		
Starting date: ___/___/______		Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Comments:				

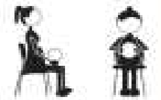
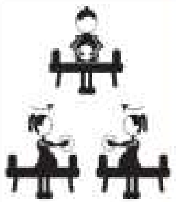
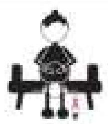
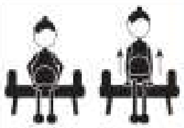
WEEK 6			
Thursday	Friday	Saturday	Sunday
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Comments:			

Starting date: ___/___/______		WEEK 7 Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______

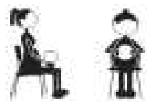
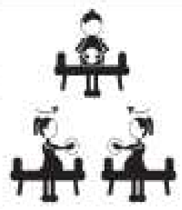
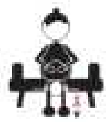
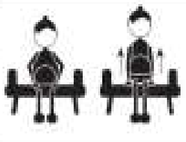
Comments:

WEEK 7 Thursday	Friday	Saturday	Sunday
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______

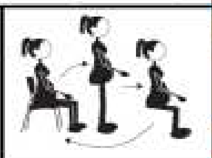
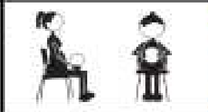
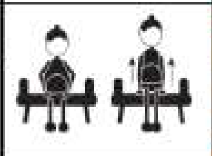
Comments:

Starting date: ___/___/______		WEEK 8 Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Comments:				

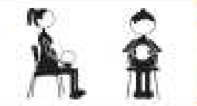
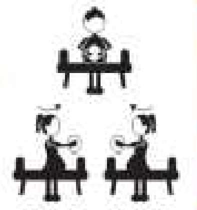
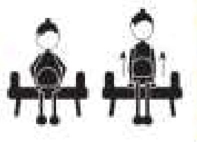
WEEK 8 Thursday	Friday	Saturday	Sunday
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Comments:			

		WEEK 9		
Starting date: ___/___/______		Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Exercise 2		Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Exercise 4		Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Exercise 5		Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Exercise 6		Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Comments:				

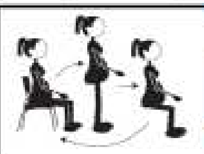
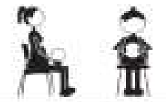
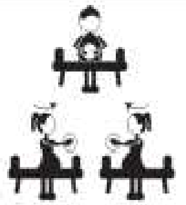
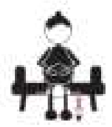
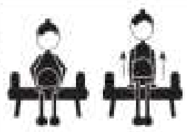
WEEK 9			
Thursday	Friday	Saturday	Sunday
Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______	Repetitions____ Sets _______
Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______	Repetitions____ Time (secs.) ___ Sets _______
Comments:			

Starting date: ___/___/______		WEEK 10 Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Comments:				

WEEK 10 Thursday	Friday	Saturday	Sunday
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Comments:			

		WEEK 11		
Starting date: ___/___/______		Monday	Tuesday	Wednesday
Exercise 1		Repetitions___ Sets ______	Repetitions___ Sets ______	Repetitions___ Sets ______
Exercise 2		Repetitions___ Sets ______	Repetitions___ Sets ______	Repetitions___ Sets ______
Exercise 3		Repetitions___ Time (secs.) ___ Sets __	Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______
Exercise 4		Repetitions___ Sets ______	Repetitions___ Sets ______	Repetitions___ Sets ______
Exercise 5		Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______
Exercise 6		Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______
Comments:				

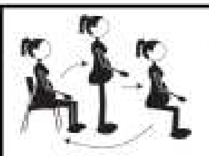
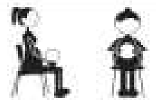
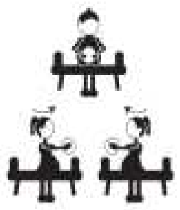
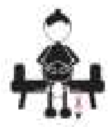
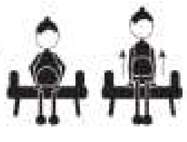
WEEK 11			
Thursday	Friday	Saturday	Sunday
Repetitions___ Sets ______	Repetitions___ Sets ______	Repetitions___ Sets ______	Repetitions___ Sets ______
Repetitions___ Sets ______	Repetitions___ Sets ______	Repetitions___ Sets ______	Repetitions___ Sets ______
Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______
Repetitions___ Sets ______	Repetitions___ Sets ______	Repetitions___ Sets ______	Repetitions___ Sets ______
Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______
Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______	Repetitions___ Time (secs.) ___ Sets ______
Comments:			

Starting date: ___/___/______		WEEK 12		
		Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______

Comments:

WEEK 12			
Thursday	Friday	Saturday	Sunday
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______

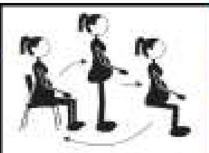
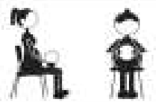
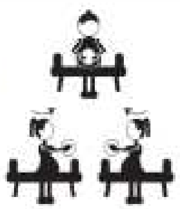
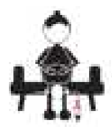
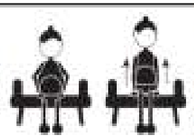
Comments:

WEEK 13				
Starting date: ___/___/______		Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______

Comments:

WEEK 13			
Thursday	Friday	Saturday	Sunday
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______

Comments:

		WEEK 14		
	Starting date: ___/___/______	Monday	Tuesday	Wednesday
Exercise 1		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 2		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 3		Repetitions____ Time (secs.) ___ Sets __	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 4		Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Exercise 5		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Exercise 6		Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Comments:				

WEEK 14			
Thursday	Friday	Saturday	Sunday
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______	Repetitions____ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______	Repetitions____ Time (secs.) ___ Sets ______
Comments:			

OPALS Study

Tommy's [Let's talk baby]

NHS Lothian